Conference on
Fire Resistant Materials:
A Compilation of Presentations
and Papers

Sponsored by NASA Headquarters
Held at
Boeing Commercial Airplane Company
Seattle, Washington
March 1-2, 1979

July 1979
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>PREFACE</td>
<td>v</td>
</tr>
<tr>
<td>AIRCRAFT FLAMMABILITY, FULL SCALE FIRE TESTS</td>
<td>1</td>
</tr>
<tr>
<td>Richard W. Bricker, Johnson Space Center</td>
<td></td>
</tr>
<tr>
<td>SEAT TEST PROGRAM</td>
<td>13</td>
</tr>
<tr>
<td>Richard W. Bricker, Johnson Space Center</td>
<td></td>
</tr>
<tr>
<td>RECENT ADVANCES IN MATERIALS TOXICOLOGY</td>
<td>27</td>
</tr>
<tr>
<td>Dan M. Russo, Southwest Foundation for Research and Education</td>
<td></td>
</tr>
<tr>
<td>STATUS OF CANDIDATE MATERIALS FOR FULL-SCALE TESTS IN THE 737 FUSELAGE</td>
<td>45</td>
</tr>
<tr>
<td>Daniel Supkis, Johnson Space Center</td>
<td></td>
</tr>
<tr>
<td>DEVELOPMENT OF PROCESSES AND TECHNIQUES FOR MOLDING FIRE RESISTANT POLYMERIC MATERIALS</td>
<td>61</td>
</tr>
<tr>
<td>Daniel Supkis, Johnson Space Center</td>
<td></td>
</tr>
<tr>
<td>DEVELOPMENT OF FIRE-RESISTANT, LOW SMOKE GENERATING, THERMALLY STABLE END ITEMS FOR COMMERCIAL AIRCRAFT AND SPACECRAFT USING A BASIC POLYIMIDE RESIN</td>
<td>71</td>
</tr>
<tr>
<td>John Gagliani, Solar Turbines International</td>
<td></td>
</tr>
<tr>
<td>GLOBAL ENCLOSURE FIRE MODELING WITH APPLICATIONS</td>
<td>93</td>
</tr>
<tr>
<td>Jay W. Stuart, Jet Propulsion Laboratory</td>
<td></td>
</tr>
<tr>
<td>ENCLOSURE FIRE DYNAMICS MODEL</td>
<td>103</td>
</tr>
<tr>
<td>Jonette Bellam, Jet Propulsion Laboratory</td>
<td></td>
</tr>
<tr>
<td>LARGE-SCALE POOL FIRE TEST RECOMMENDATIONS</td>
<td>117</td>
</tr>
<tr>
<td>C. Perry Binkston, Jet Propulsion Laboratory</td>
<td></td>
</tr>
<tr>
<td>FUSELAGE VENTILATION UNDER WIND CONDITIONS</td>
<td>127</td>
</tr>
<tr>
<td>Jay W. Stuart, Jet Propulsion Laboratory</td>
<td></td>
</tr>
<tr>
<td>FIRE RESISTANT AIRCRAFT SEAT PROGRAM</td>
<td>135</td>
</tr>
<tr>
<td>Larry A. Powell, Ames Research Center</td>
<td></td>
</tr>
<tr>
<td>A REVIEW OF BOEING INTERIOR MATERIALS AND FIRE TEST METHODS DEVELOPMENT PROGRAMS</td>
<td>167</td>
</tr>
<tr>
<td>Eugene Barry, Boeing Commercial Airplane Company</td>
<td></td>
</tr>
<tr>
<td>FIREMEN PROGRAM STATUS REPORT</td>
<td>183</td>
</tr>
<tr>
<td>Roy A. Anderton and Gerald A. Johnson, Boeing Commercial Airplane Company</td>
<td></td>
</tr>
</tbody>
</table>

---

**Miscellaneous Page Face NOT Filmed**
<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADVANCED RESIN MATRICES FOR COMPOSITES</td>
<td>223</td>
</tr>
<tr>
<td>Demetrios C. Koumides, Ames Research Center</td>
<td></td>
</tr>
<tr>
<td>A COMPARATIVE STUDY OF THE TOXICITY OF THE COMBUSTION</td>
<td>239</td>
</tr>
<tr>
<td>PRODUCTS OF TIDLAR AND A FLUORENONE-POLYESTER FILM</td>
<td></td>
</tr>
<tr>
<td>Paul J. Ferrar, University of Utah</td>
<td></td>
</tr>
<tr>
<td>FIRE AND SMOKE RETARDANT MATERIALS DEVELOPMENT</td>
<td>251</td>
</tr>
<tr>
<td>H. E. Muller, Jet Propulsion Laboratory</td>
<td></td>
</tr>
<tr>
<td>THERMOCHEMICAL MODELING</td>
<td>265</td>
</tr>
<tr>
<td>Kerri Rampalli, Jet Propulsion Laboratory</td>
<td></td>
</tr>
<tr>
<td>THE FLUORENE POLYESTER ISO FPE OF ISOVOLTA COMPANY, AUSTRIA</td>
<td>271</td>
</tr>
<tr>
<td>H. Kriiger, ISOVOLTA Company</td>
<td></td>
</tr>
<tr>
<td>CONFERENCE PARTICIPANTS</td>
<td>283</td>
</tr>
</tbody>
</table>

iv
PREFACE

The proceedings of the NASA Fire Resistant Materials Engineering (FIREMEN) Program held at Boeing Commercial Airplane Company, Seattle, Washington, on March 1-2, 1979 are reported in this NASA Conference Publication. The purpose of the conference was to discuss the results of research by the National Aeronautics and Space Administration in the field of aircraft fire safety and fire-resistant materials. The program topics include the following:

1. Large-scale testing
2. Fire toxicology
3. Polymeric materials
4. Fire modeling

Contributions to this compilation were made by representatives from NASA Headquarters, NASA-Ames Research Center, NASA-Johnson Space Center, Boeing Commercial Airplane Company, Lockheed California Company, Southwest Foundation for Research and Education, Solar Turbines International, Jet Propulsion Laboratory, University of Utah, and ISOVOLTA Company.
AIRCRAFT FLAMMABILITY

FULL SCALE POOL FIRE TESTS
OUTLINE

- PRIMARY OBJECTIVES
- THREE PHASE PROGRAM
  - OBJECTIVES
  - APPROACH
  - ENVIRONMENTAL CONSIDERATIONS
- SCHEDULE
- STATUS OF REQUIRED MATERIALS
- OPTIONS TO COMPRESS SCHEDULE
PRIMARY OBJECTIVES

- Conduct full scale test with 737 fuselage by end of 1980
- Demonstrate evacuation time increase to 5 minutes minimum
- Show that exterior fire will not penetrate an intact cabin for 5 minutes
- Show that closed cabin will not have excess smoke or temperatures above 400°F
- Demonstrate that fire in cabin opening will not propagate throughout cabin
THREE PHASE PROGRAM

- PHASE I
  CHARACTERIZE AND SIZE POOL FIRES FOR SUBSEQUENT TESTS

- PHASE II
  TEST THREE 10' X 10' FUSELAGE PANELS AT 45° ANGLE OVER POOL FIRE

- PHASE III
  CONDUCT FULL SCALE TEST(S) W/737 FUSELAGE
PHASE I - POOL FIRE CHARACTERIZATION

- OBJECTIVES

- MEASURE THERMAL OUTPUT OF 5' X 5', 10' X 10', AND 15' X 15' POOL FIRES (VARIES W/FUEL AREA AND DEPTH)

- DETERMINE FIRE GEOMETRY (HEIGHT, WIND EFFECTS)

- DETERMINE MINIMUM SIZE POOL FIRE FOR 10' X 10' PANEL TESTS (HEAT FLUX ≥ 14 BTU/FT² - SEC TEMP ≥ 1600°F)

- IMPROVE IGNITION TECHNIQUES (JET Al RELATIVELY DIFFICULT TO IGNITE)

- PROVIDE DATA FOR SELECTION OF FULL SCALE POOL FIRE FOR 737 TEST AND VERIFICATION OF FIRE SEVERITY
PHASE I

APPROACH

- USE EXISTING JSC FIREFIGHTERS TRAINING SITE (TTA HAS PORTABLE DATA ACQUISITION EQUIPMENT AVAILABLE)
- INSTRUMENT WITH CALORIMETERS AND TC'S
- UPGRADE CURRENT IGNITION TECHNIQUE TO PROVIDE RAPID FIRE SPREAD OVER POOL SURFACE (SWITCH TO JP4 IF SIGNIFICANT IGNITION PROBLEMS OCCUR)
- EIGHT TO TEN TESTS (FIVE TO TEN MINUTE DURATION)

ENVIRONMENTAL CONSIDERATIONS

- PROBLEM—AIRCRAFT FUEL FIRE PRODUCES CONSIDERABLE BLACK SMOKE
- CONSIDERATIONS
  - SMOKE CONSISTS MAINLY OF CARBON PARTICULATES
  - LOW LEVEL OF TOXIC GASES (MAINLY CO)
  - TESTS OF SHORT DURATION AND LIMITED IN NUMBER

BECAUSE OF IGNITION TECHNIQUES DEVELOPED BY TTA, AVAILABILITY OF INSTRUMENTATION AND NEED FOR REAL TIME DECISIONS AND MODIFICATION TESTS SHOULD BE RUN AT JSC

- TTA IS FUNDED TO SUPPORT PROGRAM
PHASE II - PANEL TESTS

OBJECTIVES

- PROVIDE VERIFICATION OF FIRE BARRIER MATERIALS
- VERIFY INSULATION RETENTION TECHNIQUES
- MEASURE TEMPERATURES ACROSS TEST PANEL

APPROACH

- FABRICATION AND ASSEMBLY OF COMPLETE PANEL BY AIR RESEARCH
- SELECT POOL SIZE FROM PREVIOUS TESTS
- INSTRUMENT AND INSTALL PANEL AT 45° ANGLE
- PROTECT PERIPHERY OF TEST PANEL TO PREVENT FIRE ON BACK SIDE OF PANEL
- MAXIMUM OF THREE CONFIGURATIONS
PHASE I.I - FULL SCALE TESTS

APPROACH

- REFURBISH 20 FOOT SECTION OF 737 WITH SELECTED MATERIALS (AIR RESEARCH)

- USE EXISTING SITE OF 737 AND GAS ANALYSIS SHACK (NO PERSONNEL IN SHACK DURING TEST)

- PREPARE POOL WITH BANK SAND DIKES ADJACENT TO TEST SECTION (ALPHA CONSTRUCTION)

- BUILD SAND BULKHEAD UNDER CENTER LINE OF FUSELAGE FULL LENGTH TO RESTRICT FIRE TO ONE SIDE OF FUSELAGE (ALPHA CONSTRUCTION)

- PROVIDE PROTECTION TO GAS ANALYSIS SHACK IF INDICATED FROM PHASE I FIRE GEOMETRY (INSULATED BULKHEAD, WATER SPRAY, FIRE DEPARTMENT STANDBY)
FULL SCALE TEST CONFIGURATION

TEST SECTION

POOL FIRE

SAND BARRIER

GAS ANALYSIS BUILDING
**FULL SCALE TEST SCHEDULE**

- FULL SCALE TEST OBJECTIVES SUGGEST SECOND TEST (LOW SMOKE, TEMPS> 5 MIN, VERSUS FIRE IN CABIN OPENING)

- FIRST FULL SCALE TEST SCHEDULED FOR SEPTEMBER 1980

- REFURBISHMENT FOR SECOND TEST WOULD TAKE AN ADDITIONAL 6 MONTHS (COMPATIBLE W/SCHEDULE PRESENTED 4/78)

- PACING ITEM IS INITIATION OF AIR RESEARCH CONTRACT
OUTLINE

- Objectives
- Test Configurations and Data Acquired
- Material Test Results
- Seat Test Results
- Conclusions
OBJECTIVES

- EVALUATE SEVERITY OF NEWSPAPER IGNITION SOURCE WITH CONTEMPORARY SEATS
  - DETERMINE WEIGHT LOSS AND VISUAL DAMAGE
  - DETERMINE IF IGNITION SOURCE IS SEVERE ENOUGH TO SHOW IMPROVEMENT WITH NEW MATERIAL CONFIGURATIONS

- COMPARE DAMAGE WITH JET A-1 IGNITION SOURCE

- DETERMINE IF MATERIALS FOR SEAT TESTS PASS FAR 25 AND OBTAIN LOI
TEST CONFIGURATIONS

- TESTS CONDUCTED IN STANDARD BODY FUSELAGE WITH IN FLIGHT VENTILATION

- TEST 1
  - NEWSPAPER TENTED ON CENTER SEAT OF THREE UNMODIFIED SEATS
  - NEWSPAPER IGNITED WITH MATCHES

- TEST 2
  - NEWSPAPER TENTED ON CENTER SEAT
  - ARMRESTS REMOVED
  - LEFT SEAT MOVED ADJACENT TO CENTER SEAT
  - NEWSPAPER IGNITED WITH HOT COIL

- TEST 3
  - ARMRESTS REMOVED
  - LEFT SEAT MOVED ADJACENT TO CENTER SEAT
  - 1 LITER OF JET A-1 IN 1 X 1 FOOT PAN UNDER CENTER SEAT
  - FUEL IGNITED WITH PROPANE BURNER
737 TEST SECTION

- VOLUME - 5520 ft$^3$
- VENTILATION RATE - 1500 CFM
DATA ACQUIRED

- Seats suspended from load cell for weight loss during test
- Seat weighed pre- and post-test
- Still photos before and after
- Three real time movie cameras
- One video monitor (taped)
- TC’s and calorimeters in fuselage
- Six loss of visibility measurements
- Gas analysis (O₂, CO, CO₂, hydrocarbons, HCN, HCl, and HF)
SEAT MATERIAL TEST RESULTS

- **LOI**
  - CUSHION FOAM - 26
  - WOOL BLEND UPHOLSTERY - 32
  - TWO SEAT CUSHION BACKING MATERIALS - 21 AND 28

- **FAR 25**
  - UPHOLSTERY AND BACKING MATERIALS PASS
  - CUSHION FOAM COATED SPECIMENS FAIL
  - UNCOATED FOAM PASSES DUE TO MELTING AND RECEIVING FROM FLAME
TEST RESULTS

TEST 1

- IGNITION SOURCE SLOW TO DEVELOP (TOO TIGHTLY COMPRESSED)
- AT ~5 MINUTES ARMREST IGNITED
- ARMREST IGNITED ADJACENT SEAT
- CENTER SEAT MATERIALS ~90 PERCENT BURNED
- ADJACENT SEAT ~70 PERCENT BURNED
- TOTAL MATERIAL WT. LOSS 10.5 LBS.
- TEMPERATURES IN CABIN FROM AMBIENT TO 350°F
- NO SIGNIFICANT HEAT FLUXES
- MUCH SMOKE-LOSS OF VISIBILITY AFTER SEAT INVOLVEMENT
- HIGH CO, HCN AT 10 MIN.
SEAT TEST RESULTS

TEST 2

- More rapid development of newspaper ignition source
- Center seat back ignited at ~4 minutes
- Center seat materials ~70 percent destroyed
- Adjacent seats not ignited
- Total material wt. loss ~7 lbs.
- Cabin temperatures 80°F to 240°F
- No significant heat fluxes
- Considerable smoke-loss of visibility after seat involvement
- High HCN, CO at 12 and 15 min.
SEAT TEST RESULTS

TEST 3

- More rapid involvement of seats than with newspaper
- Extensive propagation to adjacent seats (~90 percent of all 3 seats destroyed)
- Weight loss ~31.4 lbs. (>3 times that with newspapers)
- Cabin temperatures 200 to 950°F
- Burning and smoke over longer period (15 min.)
- High CO, HCN, and HCL levels
TEST 3
(1 LITER JET A-1)

TEST 2
(TENTED NEWSPAPER)

TEMP, °F

0 2 4 6 8 10 12 14
## GAS ANALYSIS RESULTS

(5 FEET HIGH ALONG CENTER LINE)

<table>
<thead>
<tr>
<th>TEST NR AND IGNITION SOURCE</th>
<th>MAXIMUM GAS LEVELS</th>
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<tbody>
<tr>
<td></td>
<td>CO</td>
</tr>
<tr>
<td></td>
<td>8 FT FWD</td>
</tr>
<tr>
<td>1 NEWSPAPER WITH ARMRESTS</td>
<td>PPM</td>
</tr>
<tr>
<td></td>
<td>1340</td>
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<td></td>
<td>T</td>
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<tr>
<td>2 NEWSPAPER WITHOUT ARMRESTS</td>
<td>PPM</td>
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<td>T</td>
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<tr>
<td>3 JET A-1 FUEL</td>
<td>PPM</td>
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*EIGHT FEET AFT — 20 INCHES HIGH AT 5.5 MIN
CONCLUSIONS

- Armrests of the seats tested highly flammable

- Newspaper ignition source will ignite seat it is on (no significant propagation to adjacent seats)

- Fuel pan fire under seat propagates to and destroys adjacent seats

- Seats tested not significantly better than with pre-68 MLS (based on fuel pan tests by FAA, AIA, and JSC)

- Newspaper ignition source will be marginal in showing significant differences with improved seat materials
RECENT ADVANCES IN MATERIALS TOXICOLOGY
OUTLINE

• OVERVIEW OF JSC FIRE TOXICOLOGY PROGRAM
  - PRINCIPAL OBJECTIVE
  - APPROACH

• LABORATORY METHODS OF ASSESSING PYROLYSIS PRODUCT TOXICITY
  - EXPERIMENT 1: COMPARISON OF TEST END POINTS
  - EXPERIMENT 2: EVALUATION OF OPERANT TECHNIQUES

• COMPARISON OF FULL-SCALE AND LABORATORY TOXICITY TESTS
  - EXPERIMENT 3: PRELIMINARY WORK

• FUTURE RESEARCH PLANS AT JSC
OVERVIEW OF JSC FIRE TOXICOLOGY PROGRAM

• PRINCIPAL PROGRAM OBJECTIVE: ASSIST IN THE DEVELOPMENT OF TOXICOLOGIC SCREENING PROCEDURES

• PROGRAM APPROACH: RESEARCH IN TWO AREAS
  - LABORATORY METHODS FOR ASSESSING PYROLYSIS PRODUCT TOXICITY
  - COMPARISON OF FULL-SCALE AND LABORATORY TOXICITY TESTS

• COMPARATIVE NATURE OF EXPERIMENTS
EXPERIMENT 1: COMPARISON OF BEHAVIORAL END POINTS

- PURPOSE: DO TEST BEHAVIORS VARY IN SUSCEPTIBILITY TO TOXIC INCAPACITATION?

- METHOD:

- RESULT:

- CONCLUSION: TUF IS A FUNCTION OF MECHANISM OF INCAPACITATION AND BEHAVIORAL REQUIREMENTS OF TEST.
LABORATORY METHODS OF ASSESSING PYROLYSIS PRODUCT TOXICITY

- EXPERIMENT 2: EMPLOY OPERANT TECHNIQUES TO ASSESS THE TOXICITY OF 2 POLYURETHAN FOAMS.
  - PURPOSE: EVALUATE OPERANT TECHNIQUES FOR TOXICOLOGICAL SCREENING.
  - METHOD:
  - RESULTS: 1. CO ANALYSIS
             2. CUMULATIVE RECORDS
             3. STATISTICAL SUMMARY
FIGURE 1. Mean CO Concentration ± 1 S.E. as a Function of Test Time.
FIGURE 2. Cumulative Records Showing Effect of Foam Pyrolysis on Signalled (Discriminative) Shock Avoidance. (Upward Displacement of Line Indicates Bar Response and Downward Slash Represents Shock Occurrence.)
TABLE 1. Pyrolysis-Induced Changes in Operant Performance. Each Cell Represents The Results of a Paired T-Test. NS = No Significant Change (p > .05), † = Significant Increase (p < .05), ‡ = Significant Decrease (p < .05)

<table>
<thead>
<tr>
<th></th>
<th>FIRE-RETARDED FOAM</th>
<th></th>
<th>CONVENTIONAL FOAM</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TEST MIN.</td>
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<td>TEST MIN.</td>
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<td></td>
<td>5  10  15  20  25  30  TOT</td>
<td></td>
<td>5  10  15  20  25  30  TOT</td>
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<tr>
<td>RATES (PER MIN)</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>AVOIDANCE</td>
<td>† † † † † † †</td>
<td></td>
<td>† † † † † † †</td>
<td></td>
</tr>
<tr>
<td>ESCAPE</td>
<td>NS † NS NS NS NS NS</td>
<td></td>
<td>NS † NS NS NS NS NS</td>
<td></td>
</tr>
<tr>
<td>NO. OF UNESCAPED SHOCKS</td>
<td>† † NS NS NS †</td>
<td></td>
<td>NS NS NS NS NS NS NS</td>
<td></td>
</tr>
<tr>
<td>% ESCAPE</td>
<td>† † NS NS NS NS †</td>
<td></td>
<td>NS NS NS NS NS NS NS</td>
<td></td>
</tr>
<tr>
<td>SHOCK TIME</td>
<td>† † NS NS NS NS †</td>
<td></td>
<td>NS NS NS NS NS NS NS</td>
<td></td>
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</table>

|                      | TEST MIN.          |                      | TEST MIN.          |                      |
|                      | 5  10  15  20  25  30  TOT |                      | 5  10  15  20  25  30  TOT |                      |
| SIGNALLED (DISCRIMINATIVE) AVOIDANCE |                    |                      |                    |                      |
|                      | 10 TRIAL BLOCKS    |                      |                    |                      |
| AVOIDANCE            | † † † † † † †       |                     | † † † † † † †       |                     |
| ESCAPE               | NS NS NS NS NS NS   |                     | NS NS NS NS NS NS   |                     |
| NO. OF UNESCAPED SHOCKS | NS NS † † † †       |                     | NS † † NS NS NS NS NS |                     |
| SHOCK TIME           | † † † † NS NS NS NS |                     | † † † † NS NS NS NS NS |                     |
CONCLUSIONS FROM EXPERIMENT 2

Disadvantages: 1. Training time
2. Data base established with alternative techniques

Advantages: 1. Remote monitoring of behavior
2. Continuous monitoring of behavioral changes
3. Quantify behavioral changes
4. Correlation with gas concentrations
EXPERIMENT 3: PRELIMINARY WORK

- PURPOSE: DETERMINE ANIMAL SURVIVABILITY IN FULL-SCALE TESTS
- METHOD:
- RESULTS: 1. TEMPERATURE PROFILES
  2. CO AND HCN ANALYSES
  3. SURVIVAL AND COHb ANALYSES
7x7 TEST SECTION

- VOLUME - 3920 FT³
- VENTILATION RATE - 1500 CFM
CARBON MONOXIDE CONCENTRATIONS

% CO,
PPM

16 FT FWD
5 FT HIGH

8 FT FWD
5 FT HIGH

0 FT FWD
30 IN HIGH

TIME, MIN

0
5
10
15
CONCLUSIONS FROM EXPERIMENT 3

1. FULL-SCALE VARIATIONS IN TEMPERATURE AND GAS CONCENTRATIONS

2. TOXICITY ASSESSMENTS LIKELY TO VARY

3. STANDARDIZATION AND REFINEMENT OF TECHNIQUES
FUTURE RESEARCH PLANS AT JSC

1. FURTHER COMPARISONS OF LABORATORY METHODS: SEATING MATERIAL TESTS

2. FULL-SCALE TOXICITY TESTS: USE OF DIFFERENT BEHAVIORAL TASKS

3. COMPARISON OF FULL-SCALE AND LABORATORY TOXICITY ASSESSMENTS

4. DELINEATION OF LABORATORY METHODS
STATUS OF CANDIDATE MATERIALS FOR FULL-SCALE TESTS IN THE 737 FUSELAGE
OBJECTIVES

- INCREASED PASSENGER EVACUATION TIME TO A MINIMUM OF 5 MINUTES FROM COMMERCIAL AIRCRAFT IN CASE OF A FIRE

- PREVENT AN EXTERNAL FIRE FROM ENTERING CLOSED CABINS FOR 5 MINUTES BY USING FIRE BARRIER MATERIALS IN THE EXTERIOR WALL

- DEMONSTRATE THAT A CLOSED CABIN WILL NOT REACH 400°F NOR CONTAIN SMOKE OR TOXIC GASES UP TO 400°F

- PROVE THAT A FIRE NEAR A CABIN OPENING WILL NOT PROPAGATE THROUGH THE CABIN FOR A MINIMUM OF 5 MINUTES
MATERIALS STATUS

- SEAT CUSHIONS
  - Fire barrier configuration using present foam (AMES-DAC)
  - Present polyimide foam meets majority of seat requirements (JSC-SOLAR)
  - Initial evaluation of polyimide foam by Fairchild-Burns indicated the foam is functional in seats
  - Polyimide foam samples provided Weber Aircraft Co. for additional evaluation

- UPHOLSTERY AND ASSOCIATED SEAT MATERIALS
  - Wool or wool-leavel blends upholstery fabrics currently used are satisfactory
  - Disposable head rest towels are fire-retardant and available
  - Fire-retardant cotton ticking for cushions meets aircraft requirements and is available
  - Fire-retardant leather arm rest and trim meets JSC flammability requirements

- WALL AND CEILING PANELS
  - Phenolic/ fiberglass laminates available from Ames Research and Lockheed development programs
  - Evaluation of initial production runs of Fluorel glass will result in an additional panel
MATERIALS STATUS (CONTINUED)

- FLOOR PANELS
  - POLYIMIDE FOAM FILLED HONEYCOMB CORE WITH PHENOLIC/GLASS FACE SHEETS MEETS ALL BOEING FLOOR SPECIFICATIONS
  - SAME CONFIGURATION WITHSTOOD BOEING OIL BURNER 15 MINUTES
  - IMPROVED FIRE RETARDANT ADHESIVE NEEDED

- CARPET AND CARPET UNDERLAY
  - NO DEVELOPMENT PROGRAMS ANTICIPATED
  - CURRENT STATE-OF-THE-ART WOOL AND WOOL BLENDS MATERIALS ADEQUATE
  - POLYIMIDE FOAM APPEARS ADEQUATE FOR UNDERLAY

- WINDOWS
  - Ames developed windows char, eliminate radiant heat and resist burnthrough for 4-5 minutes

- CARGO BAY LINERS
  - POLYIMIDE/GLASS AND PHENOLIC/GLASS LAMINATES CURRENTLY A NON-FUNDED DEVELOPMENT EFFORT BY NORDAM AND CIBA-GEIGY
  - SOLAR CAPABLE OF DEVELOPING TECHNOLOGY FOR 50K

- INSULATION BAGGING
  - CERAMIC FIBER SCRIM COMBINED WITH PRESENT ALUMINIZED TEDLAR BAGS TO RETAIN THERMAL-ACOUSTICAL INSULATION
  - CONFIGURATIONS TO BE TESTED IN SEMI-FULL SCALE TESTING IN FUSELAGE CROSS-SECTIONS
MATERIALS STATUS

- THERMAL ACOUSTICAL INSULATION
  - LITAFLEx ASBESTOS FOAM MEETS WEIGHT, TEMPERATURE DIFFERENTIAL, AND FIRE BARRIER PROPERTIES BUT LOW IN ACOUSTICAL ATTENUATION
  - POLYIMIDE FOAM MEETS WEIGHT REQUIREMENTS ONLY
  - PREVIOUS POLYIMIDE SAMPLES, TOO LOW IN DENSITY, FAILED TO MEET ACOUSTIC AND FIRE BARRIER REQUIREMENTS
  - RECENT SAMPLES OF HIGHER DENSITY SHOW IMPROVEMENT IN FIRE BARRIER PROPERTIES
  - CERAMIC AND CERAMIC-ASBESTOS FOAM UNDER DEVELOPMENT, BY RAYBESTOS-MANHATTAN
TEMPERATURES DURING TEST OF TYPICAL STANDARD BODY FUSELAGE CROSS SECTION:

- Flame Temperature
- Outer Skin Melt Through (30 sec)
- Inner Skin Melt Through (1 min 40 sec)
- Insulation Penetration (1 min 25 sec)

TEMP, °F

TIME, MIN
TEMPERATURES DURING TEST OF TYPICAL WIDE BODY FUSELAGE CROSS SECTION

- Outer skin melt through (45 sec)
- Insulation penetration (1 min 20 sec)
- Inner skin surface burning (observed)
- Decorative laminate burning (observed at 2 min 10 sec)
- Decorative laminate melting (observed at 2 min)
TEMPERATURES DURING TEST OF NARROW BODY FUSELAGE CROSS SECTION
(WITH DECO .040/DECORATIVE FILM INNER SKIN)

TEMP, °F

TIME, MIN

OUTER SKIN MELT THRU (36 SEC)
INSULATION PENETRATION (1 MIN 5 SEC)
INNER SKIN DECORATIVE FILM BURNING (OBSERVED) (1 MIN 30 SEC)
INNER SKIN DECORATIVE FILM MELTING (OBSERVED) (~ MIN 13 SEC)

INSULATION
OIL BURNER
OUTER SKIN
INNER WALL PANEL
DECORATIVE FILM
T.C.'S
TEMPERATURES DURING TEST OF NARROW BODY FUSELAGE CROSS SECTION
(WITH .005 GRAFOIL/.1 1.5 LB FIBERGLASS/.005 GRAFOIL/DEC0 .040 DECOPATIVE FILM INNER SKIN)

OUTER SKIN MELT THRU (33 SEC)
INSULATION PENETRATION (3 MIN)
INNER SKIN DECORATIVE FILM MELTING (OBSERVED) (3 MIN 10 SEC)
INNER SKIN DECORATIVE FILM BURNING (OBSERVED) (4 MIN 3 SEC)

TIME, MIN
TEMP., °F

OUTER SKIN
INSULATION
OIL BURNER
DEDECATIVE FILM
INNER WALL PANEL

23 T.C.'S
TEMPERATURES DURING TEST OF NARROW BODY FUSELAGE CROSS SECTION

(WITH .005 GRAFOIL/3" POLYIMIDE THERMO/AcouSTICAL FCAM/.005 GRAFOIL/.040 DECO DECORATIVE FILM INNER SKIN)

<table>
<thead>
<tr>
<th>Time, Min</th>
<th>Temp, °F</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>66</td>
</tr>
<tr>
<td>2</td>
<td>1000</td>
</tr>
<tr>
<td>3</td>
<td>1500</td>
</tr>
<tr>
<td>4</td>
<td>2000</td>
</tr>
</tbody>
</table>

- Outer Skin Melt Thru (30 Sec)
- Outer Skin Deco Decorative Film Melting (Observed) (1 Min 55 Sec)
- Inner Skin Deco Decorative Film Burning (Observed) (2 Min 55 Sec)
TEMPERATUEs DURING TEST OF NARROW BODY FUSELAGE CROSS SECTION
(WITH .015 GRAFOIL/(4) 1.5 LBFT^3 FIBERCLASS/.040 DECO DECORATIVE FILM INNER SKIN)
TEMPERATURES DURING TEST OF NARROW BODY FUSELAGE CROSS SECTION
(WITH (1) 1.5" THICK K-25 LITOFLEX FOAM/040 DECORATIVE FILM & ALUMINUM INNER SKIN)

1. OUTER SKIN MELT THRU (32 SEC)
2. INSULATION BAGGING MELT IGNITION
3. INNER SKIN DECORATIVE FILM SLOW MELT (OBSERVED) (4 MIN 30 SEC)

CIL BURNER
1 2 3 4 T.C.'S
INSULATION
OUTER SKIN
INNER SKIN
DECORATIVE FILM
SUMMARY

- SEAT CUSHIONS
  - Final configuration contingent on test results from SwRI and DAC
  - Polyimide foam a promising candidate

- Upholstery and associated seat materials
  - Textile development for upholstery and associated seat materials prohibitive in cost and time
  - The best state-of-the-art materials available at the scheduled time will be procured

- Wall and ceiling panels
  - Lockheed developed panels offer weight savings over aluminum
  - Forty Lockheed Phenolic/Glass panels being supplied under present contract
  - Fluorel/Glass panels have superior acoustical and fire barrier properties

- Floor panels
  - Most promising is rigid polyimide foam filled honeycomb core with Phenolic/Glass face sheets

- Carpet and carpet underlay
  - Commercially available wool and wool blends are adequate
  - Carpets and underlay not significantly involved in aircraft fires during evacuation
  - Polyimide foam underlay provides good fire barrier
**SUMMARY (CONTINUED)**

- **WINDOWS**
  - AMES-INDUSTRY DEVELOPMENT ONLY IMPROVEMENT AVAILABLE

- **CARGO BAY LINERS**
  - POLYIMIDE/GLASS AND PHENOLIC/GLASS DEVELOPMENTS APPEAR PROMISING
  - ADVANCED LINERS NOT ESSENTIAL FOR FULL-SCALE TESTS IF FUSELAGE FIRE BARRIER PROVES ADEQUATE; NEW FLOOR PANEL PROVIDES EXCELLENT BARRIER TO FIRES BENEATH THE CABIN

- **INSULATION BAGGING**
  - CERAMIC FIBER SHOWS PROMISE TO HOLD THERMAL-ACOUSTICAL INSULATION IN PLACE WHEN TEDLAR BURNS OFF

- **THERMAL-ACOUSTICAL INSULATION**
  - POLYIMIDE FOAM PROMISING CANDIDATE IF ACOUSTICAL AND FIRE BARRIER PROPERTIES CAN BE UPGRADED
  - CERAMIC FOAM MAY BE CANDIDATE IF DEVELOPMENT CAN KEEP PACE WITH FULL-SCALE TEST SCHEDULE
  - LITAFLEX AND CERAMIC-ASBESTOS MAY BE INCLUDED IF OSHA REQUIREMENTS CAN BE MET
  - GRAPHOIL PROVIDES ADDITIONAL FIRE BARRIER PROTECTION FOR THERMAL-ACOUSTICAL INSULATION BUT IS EXPENSIVE
DEVELOPMENT OF PROCESSES AND TECHNIQUES FOR MOLDING

FIRE RESISTANT POLYMERIC MATERIALS

D. SUPRIS

CONTRACT NAS 9-15405
LOCKHEED-CALIFORNIA COMPANY
BURBANK, CALIFORNIA
OBJECTIVES

- SELECT FIRE-RETARDANT MATERIALS FOR MOLDING AIRCRAFT PARTS

- EVALUATE MATERIALS FOR FLAMMABILITY AND THERMAL STABILITY

- DEVELOP PROCESSES AND TECHNIQUES FOR FORMING THESE MATERIALS BY COMPRESSION, INJECTION AND THERMOFORM MOLDING
<table>
<thead>
<tr>
<th>Property</th>
<th>Lac.22-1339 Phenolic Glass</th>
<th>CIBA/GEIGY FIBER DUX 917 Phenolic/Glass</th>
<th>N/RMCO 8250 Phenolic Glass</th>
<th>Solar Int'l Polymide Glass</th>
<th>3M Fluorel</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density, GM/CC</td>
<td>1.90</td>
<td>1.90</td>
<td>1.90</td>
<td>1.50</td>
<td>≈ 1.75</td>
<td>1.30 (Max)</td>
</tr>
<tr>
<td>Heat Deflection, °C @ 264/PSI</td>
<td>200</td>
<td>175</td>
<td>170</td>
<td>204</td>
<td>≈ 180</td>
<td>121 (Min)</td>
</tr>
<tr>
<td>Flammability Test FAR 25.853 60 Sec. Vertical</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flame Time, sec.</td>
<td>3</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>15 (Max)</td>
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<tr>
<td>Burn length, in.</td>
<td>1.32</td>
<td>2.44</td>
<td>1.52</td>
<td>1.20</td>
<td>1.08</td>
<td>6 (Max)</td>
</tr>
<tr>
<td>Burntime-Cippings, sec.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3 (Max)</td>
</tr>
<tr>
<td>Smoke Obsuration Ds(6Min)Flaming</td>
<td>8.0</td>
<td>8.8</td>
<td>8</td>
<td>3</td>
<td>10</td>
<td>75 (Max)</td>
</tr>
<tr>
<td>Limiting Oxygen Index</td>
<td>40</td>
<td>30</td>
<td>40</td>
<td>60</td>
<td>60</td>
<td>35 (Min)</td>
</tr>
<tr>
<td>Thermogravimetric Analysis °C</td>
<td>390</td>
<td>390</td>
<td>390</td>
<td>590</td>
<td>476</td>
<td>205 (Min)</td>
</tr>
<tr>
<td>Material Cost, $/LB</td>
<td>2.25</td>
<td>6.75</td>
<td>5.60</td>
<td>11.25</td>
<td>8.00</td>
<td>20% increase over present quantities (Max) up to present materials</td>
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<tr>
<td>Handling Properties</td>
<td>Adequate</td>
<td>Adequate</td>
<td>Adequate</td>
<td>Currently limited to simple parts</td>
<td>Adequate</td>
<td></td>
</tr>
<tr>
<td>Availability</td>
<td>Production Quantities</td>
<td>Production Quantities</td>
<td>Production Quantities</td>
<td>Limited Production</td>
<td>Limited Production</td>
<td>Production Quantities</td>
</tr>
</tbody>
</table>
DISCUSSION OF RESULTS

COMPRESSION HOLDING

- PHEROLIC HOLDINGS MEET FLAMMABILITY, SMOKE, AND THERMAL REQUIREMENTS

- TEDLAR DECORATIVE FILM INCREASES SMOKE AND BURN LENGTH

- SOLAR POLYIMIDE MOLDABLE BUT REQUIRES PROCESSING INSTRUCTION TO CONVERTERS

- SELECTION OF FLUOREL/GLASS FABRIC OR FLUOREL/GLASS MAY CONTINGENT ON EVALUATION OF PRODUCTION RUNS
## INJECTION MOLDING DATA

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Density, Gm/CC</td>
<td>1.21</td>
<td>1.19</td>
<td>1.29</td>
<td>1.37</td>
<td>1.30 (Max)</td>
</tr>
<tr>
<td>Heat Deflection °C @ 264 psi</td>
<td>132</td>
<td>170</td>
<td>204</td>
<td>190</td>
<td>121 (Min)</td>
</tr>
<tr>
<td>Flammability Test FAR 25.853</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60 Sec. Vertical Flametime, Sec</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>15 (Max)</td>
</tr>
<tr>
<td>Burn length, Inches</td>
<td>3.00</td>
<td>2.48</td>
<td>2.8</td>
<td>3.40</td>
<td>6 (Max)</td>
</tr>
<tr>
<td>Burntime-Drippings, Sec</td>
<td>2</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>3 (Max)</td>
</tr>
<tr>
<td>Smoke Obscuration D₅ (6 Min) Flaming</td>
<td>110</td>
<td>90</td>
<td>3.2</td>
<td>20</td>
<td>75 (Max)</td>
</tr>
<tr>
<td>Limiting Oxygen Ind.</td>
<td>35</td>
<td>33</td>
<td>38</td>
<td>36</td>
<td>35 (Min)</td>
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<tr>
<td>Thermogravimetric Analysis °C</td>
<td>440</td>
<td>329</td>
<td>870</td>
<td>299</td>
<td>205 (Min)</td>
</tr>
<tr>
<td>Material Cost $/LB</td>
<td>2.50</td>
<td>8.00</td>
<td>15.00</td>
<td>8.00</td>
<td></td>
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<tr>
<td>IZOD Impact, Notched FT-LBS/INCH</td>
<td>10</td>
<td>3</td>
<td>1.2</td>
<td>1.6</td>
<td>3.0 (Min)</td>
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<tr>
<td>Tensile Strength PSI, Min.</td>
<td>8500</td>
<td>12,000</td>
<td>10,400</td>
<td>12,000</td>
<td>6000 (Min)</td>
</tr>
<tr>
<td>Elongation, %</td>
<td>90</td>
<td>60</td>
<td>60</td>
<td>10</td>
<td>20 (Min)</td>
</tr>
</tbody>
</table>
DISCUSSION OF RESULTS

INJECTION MOLDING

- Polyethersulfone (PES) and polyphenylsulfone (PPS) have better flammability properties than Lexan 940.

- PES and PPS materials and processing costs much higher than Lexan 940.

- Monsanto's polyester fails flammability tests.

- Lexan 940 melts and drips burning particles.
## THERMOFORM DATA

<table>
<thead>
<tr>
<th>Property</th>
<th>Polycarbonate Lexan F-6000</th>
<th>Polycarbonate Lexan EF-6000</th>
<th>Polyethersulfone PES KM-1</th>
<th>Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density, Gm/CC</td>
<td>1.21</td>
<td>1.21</td>
<td>1.37</td>
<td>1.40 (Max)</td>
</tr>
<tr>
<td>Heat Deflection °C @ 264 psi</td>
<td>132</td>
<td>122</td>
<td>190</td>
<td>121 (Min)</td>
</tr>
<tr>
<td>Flammability Test FAR 25.853</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flame time, seconds</td>
<td>4</td>
<td>97</td>
<td>0</td>
<td>15 (Max)</td>
</tr>
<tr>
<td>Burn length, inches</td>
<td>3.0</td>
<td>7.4</td>
<td>3.4</td>
<td>6 (Min)</td>
</tr>
<tr>
<td>Burntime-drippings, sec.</td>
<td>1.0</td>
<td>1.0</td>
<td>0</td>
<td>3 (Max)</td>
</tr>
<tr>
<td>Smoke Obscuration D_{50} (6 Min) Flaming</td>
<td>110</td>
<td>120</td>
<td>20</td>
<td>75 (Max)</td>
</tr>
<tr>
<td>Limiting Oxygen Index</td>
<td>33.5</td>
<td>33</td>
<td>36</td>
<td>35 (Min)</td>
</tr>
<tr>
<td>Thermogravimetric Analysis °C</td>
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<td>440</td>
<td>550</td>
<td>205 (Min)</td>
</tr>
<tr>
<td>Material Cost $/LB</td>
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<td>3.00</td>
<td>8.00</td>
<td></td>
</tr>
<tr>
<td>Availability</td>
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<td></td>
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<tr>
<td>IZOD Impact, Notched FT-LBS/INCH</td>
<td>10</td>
<td>12</td>
<td>1.3</td>
<td>3.0 (Min)</td>
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<tr>
<td>Tensile Strength psi minimum</td>
<td>9,800</td>
<td>9,600</td>
<td>12,000</td>
<td>6,000 (Min)</td>
</tr>
<tr>
<td>Elongation %</td>
<td>75</td>
<td>76</td>
<td>3</td>
<td>20 (Min)</td>
</tr>
<tr>
<td>180° Peel/LB/INCH</td>
<td>10</td>
<td>10</td>
<td>7</td>
<td>8 (Min)</td>
</tr>
<tr>
<td>Cleaner and Solvent Resist.</td>
<td>Fair</td>
<td>Fair</td>
<td>Good</td>
<td>Good</td>
</tr>
</tbody>
</table>
SUMMARY OF RESULTS

THERMOFORM

- POLYCARBONATE EP 6000 CLEANABILITY AND FLAMMABILITY PROPERTIES DO NOT MEET REQUIREMENTS

- POLYCARBONATE FC000 BETTER BUT MELTS AND DRIPS DURING PARTICLES

- POLYETHERSULFONE SATISFACTORY BUT SPECIAL EXPENSIVE DIES ARE REQUIRED FOR THERMOFORMING
CONCLUSIONS

COMPRESSION MOLDING

- PHENOLICS MEET ALL REQUIREMENTS
- PHENOLIC FORMULATIONS COMMERCIALY AVAILABLE FOR FY 80 TESTS
- SELECTION OF ONE OF TWO FLUOREL/GLASS CONFIGURATIONS TO BE MADE AFTER EVALUATION OF PRODUCTION RUNS
- FLUOREL/GLASS MATERIALS OFFER ADVANTAGES IN WEIGHT SAVINGS, ACOUSTICS, AND FIRE BARRIER PROPERTIES

INJECTION MOLDING

- PES KM-1, POLYETHERSULFONE MAY SHOW PROMISE FOR REPLACING POLYCARBONATE IF DEVELOPMENT CONTINUES

THERMOFORMING

- NO THERMOFORMABLE MATERIALS HAS BEEN IDENTIFIED THAT MEETS JSC REQUIREMENTS
This presentation is divided into four parts. The first part covers experimental data pertinent to flexible resilient foams followed in order by low density wall panels, high strength floor panels and thermal acoustical insulation.

The schedule which covers each task under study is shown in Figure 1 and the interrelations between the various products and tasks are shown in Figure 2. The tasks and the objectives of the phase of the program dealing with flexible resilient foams are shown in Figure 3.

These objectives were achieved by modification of the resin compositions through advanced synthesis and by optimization of all the process parameters. Modification of the basic prepolymer was carried out by alteration of the resins with aromatic and aliphatic diamines. The corresponding terpolyimide foams obtained were then evaluated for the most critical parameters as shown in Figure 4 and Figure 5. As reported, aromatic terpolyimide foams did not produce the desired compression set properties (15% loss maximum after 24 hours at 90% compression) and were eliminated from further study.

The properties of foam derived from terpolyimides modified with aliphatic diamines approached the requirements for compression set (see Group IV) and met the fatigue requirements.

Next, an evaluation of the effect of the heterocyclic diamine component on the compression set of the foams was carried out. The data of Figure 6 show that higher ratio of the heterocyclic diamine produces foams with improved compression set properties, however when ratios higher than 0.4 were used the foams obtained were highly reticulated and not suitable for sealing applications.
The two candidates selected, specifically the 1701-1 and 1702-1 were further evaluated to study the contribution of surfactants on compression set properties. These data are shown in Figure 7 where the improved properties of the 1701-1 foams are clearly shown. At this point of the program, four polyimides precursors were selected for further evaluation in further studies.

The efforts were continued with evaluation of the foaming process parameters. The foaming process consists of simply placing the powder precursor on a suitable substrate followed by foaming in a microwave oven. The expanded mass is then heat cured at 500°-550°F to obtain resiliency and flexibility.

The foaming parameters studied were:

- Power output
- Powder loading
- Pre. temperature
- Preheat time
- Foaming time
- Curing temperature

Figure 8 shows that power output in the range of 2.5 to 10 kW produces foaming but higher power outputs are desirable since they cause incipient curing. The effect of powder loading on the foaming behavior of polyimide precursors is shown in Figure 4. Powder loadings higher than 2.4 Kg/m² are essential. The powder precursor does not have to be preheated as shown in Figure 10, however when the preheating time is extended and the temperature is maintained at 250°F improved compression set properties are obtained (Figure 11).

The foaming time in the high frequency field has also been found to be critical as shown in Figure 12 where improved compression properties are achieved by using higher power outputs and longer foaming time. The last step in the preparation of the polyimide foam involves curing the expanded mass to achieve flexibility and resiliency.
The data of Figure 13 show that higher temperature and longer curing time cause foam degradation and poor compression set properties. The data points represent an average of six determinations carried out on large size foams (1000 g of powder precursors). This concludes the work carried out in the task dealing with flexible resilient foams.

The next study involved evaluation of processes and compositions to fabricate wall panels. The tasks and objectives are shown in Figure 14. Optimization of the polyimide compositions previously developed was achieved with the development of rigid foams meeting the density requirements. This study was continued with development of new techniques to produce low density panels in a one-step microwave process as shown in Figure 15. The precursor and additives are mixed, spread over a substrate and foamed in a microwave cavity by restricting the rise. The finished rigid panel is characterized by possessing low density core and high density skins.

The same technology is now being used to produce high strength floor panels. The tasks and objectives of this task are shown in Figure 16.

A major task of this program was the development of thermal acoustical polyimide materials to replace conventional glass batting insulation. The tasks and objectives of this last study are shown in Figure 17. The studies dealing with advanced synthesis and with foaming studies carried out in the task dealing with flexible resilient foams are completely applicable to fabrication of polyimide foams for use in thermal acoustical insulation. The optimization of glass batting and foams was then initiated. Figure 18 shows the effect of polyimide foam coatings on the burnthrough resistance of PF-105-700 fiberglass batting. The coatings were applied by spray techniques using liquid polyimide precursors and foamed at 550°F. As shown, polyimide coatings improve the burnthrough resistance of the fiberglass batting at any resin loading. The burnthrough requirements were met at a loading of 0.048 Kft/m². The tests were made with a Meker burner and carried out until burnthrough occurred.

A second approach to the problem involved modification of the polyimide foams with additives to produce improved fire resistance. Figure 19 shows the effect
of a combination of glass microballoons and glass strands on the burnthrough resistance of polyimide foams. The filled foam did not fail after 10 minutes exposure to the Maker burner, while the unfilled foam failed in 2.5 minutes. The two candidate materials, the polyimide coated fiberglass batting and the filled polyimide foams were then tested in the NASA-JSC Fire Rig, but did not meet the minimum burnthrough requirements (5 minutes). Failure appeared to be more mechanical due to thermal cracking, than to material failure.

To reduce the thermal stresses and improve the burnthrough resistance, new crosslinked polyimide foams have been developed which are undergoing evaluation.

The program is continuing with the major tasks listed in Figure 20.
Development of Fire-Resistant, Low Smoke Generating, Thermally Stable End Items for Commercial Aircraft and Spacecraft Using a Basic Polyimide Resin

Submitted to:

National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
Houston, Texas 77058

Attn: Norman R. Lamb
Mail Code: BC721 (3)

SOLAR TURBINES INTERNATIONAL
An Operating Group of International Harvester
2200 Pacific Highway, P.O. Box 80966, San Diego, California 92138
## Product I - Resilient Foam Technology
- Advanced Polymer Synthesis
- Foaming Studies
- Purchase Microwave Oven (GFE)
- Scale-up Processes
- Characterization & Selection
- Sample Preparation

## Product II - Low Density Wall and High Strength Floor Panels
### Low Density Wall Panels
- Optimization of Rigid Polymer Panels
- Low Density Core, High Density Skin Panels
- Optimization of Low Density Core Technology
- New Configurations & Reinforcements
- Process Parameters, Screening of Candidates
- Advanced Testing
- Sample Preparation
- High Strength / floor Panels
- Optimization of Rigid Polymer Foam Panels
- New Configurations
- Process Parameter Study / Screening of Candidates
- Advanced Testing
- Sample Preparation

## Product III - Thermal Acoustical Insulation
- Advanced Polymer Synthesis
- Foaming Studies
- Cutting Process for Glass Fiber Mats
- Prototype Preparation and Selection
- Final Characterization
- Sample Preparation

## Reporting and Coordination
- Monthly Progress Reports
- Mid-Term Report
- Final Report, Draft
- Final Report, Submittal
- Quarterly Reports
- Mid-Term Presentation
- End of Contract Presentation

### Figure 1. Program Schedule
Figure 2. Program Flow Diagram
FLEXIBLE RESILIENT FOAMS

TASKS

- ADVANCED POLYIMIDE SYNTHESIS
- FOAMING STUDIES
- SCALE-UP PROCESSES

OBJECTIVES

- IMPROVEMENT OF COMPRESSION SET AND FATIGUE PROPERTIES
- OPTIMIZATION OF ALL PROCESSES FROM RESIN SYNTHESIS TO FINAL FOAMING
- SCALE-UP TO LARGE SIZE FOAMS

Figure 3. Flexible Resilient Foams
<table>
<thead>
<tr>
<th>Foam Number</th>
<th>Composition</th>
<th>% in Date</th>
<th>Density</th>
<th>Resilience</th>
<th>% Loss After 30 Minutes Recovery</th>
<th>Type of Foam</th>
</tr>
</thead>
<tbody>
<tr>
<td>1710-1-4</td>
<td>60AP:30HN:10MPD</td>
<td>1.0 3.2 45 0.05</td>
<td>10.8 1.95</td>
<td>30-70</td>
<td>50.0</td>
<td>Flexible, resilient, good homogeneous cellular structure, some striations</td>
</tr>
<tr>
<td>1710-1-5</td>
<td>60AP:30HN:10MPD</td>
<td>1.0 3.0 55 0.15</td>
<td>10.8 1.95</td>
<td>30-70</td>
<td>50.0</td>
<td>Flexible, resilient, good homogeneous cellular structure</td>
</tr>
<tr>
<td>1710-1-6</td>
<td>60AP:30HN:10MPD</td>
<td>3.0 3.0 40 0.30</td>
<td>10.8 1.95</td>
<td>30-70</td>
<td>50.0</td>
<td>Flexible, resilient, good homogeneous cellular structure</td>
</tr>
<tr>
<td>1710-1-7</td>
<td>60AP:30HN:10MPD</td>
<td>1.0 3.0 45 0.05</td>
<td>10.8 1.95</td>
<td>30-70</td>
<td>50.0</td>
<td>Flexible, resilient, good homogeneous cellular structure</td>
</tr>
<tr>
<td>1710-1-8</td>
<td>60AP:30HN:10MPD</td>
<td>1.0 3.0 55 0.15</td>
<td>10.8 1.95</td>
<td>30-70</td>
<td>50.0</td>
<td>Flexible, resilient, good homogeneous cellular structure</td>
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<tr>
<td>1710-1-9</td>
<td>60AP:30HN:10MPD</td>
<td>1.0 3.0 40 0.30</td>
<td>10.8 1.95</td>
<td>30-70</td>
<td>50.0</td>
<td>Flexible, resilient, good homogeneous cellular structure</td>
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<tr>
<td>1710-1-10</td>
<td>60AP:30HN:10MPD</td>
<td>1.0 3.0 45 0.05</td>
<td>10.8 1.95</td>
<td>30-70</td>
<td>50.0</td>
<td>Flexible, resilient, good homogeneous cellular structure</td>
</tr>
<tr>
<td>1710-1-11</td>
<td>60AP:30HN:10MPD</td>
<td>1.0 3.0 55 0.15</td>
<td>10.8 1.95</td>
<td>30-70</td>
<td>50.0</td>
<td>Flexible, resilient, good homogeneous cellular structure</td>
</tr>
<tr>
<td>1710-1-12</td>
<td>60AP:30HN:10MPD</td>
<td>1.0 3.0 40 0.30</td>
<td>10.8 1.95</td>
<td>30-70</td>
<td>50.0</td>
<td>Flexible, resilient, good homogeneous cellular structure</td>
</tr>
<tr>
<td>1710-1-13</td>
<td>60AP:30HN:10MPD</td>
<td>1.0 3.0 45 0.05</td>
<td>10.8 1.95</td>
<td>30-70</td>
<td>50.0</td>
<td>Flexible, resilient, good homogeneous cellular structure</td>
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<tr>
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<td>60AP:30HN:10MPD</td>
<td>1.0 3.0 55 0.15</td>
<td>10.8 1.95</td>
<td>30-70</td>
<td>50.0</td>
<td>Flexible, resilient, good homogeneous cellular structure</td>
</tr>
<tr>
<td>1710-1-15</td>
<td>60AP:30HN:10MPD</td>
<td>1.0 3.0 40 0.30</td>
<td>10.8 1.95</td>
<td>30-70</td>
<td>50.0</td>
<td>Flexible, resilient, good homogeneous cellular structure</td>
</tr>
<tr>
<td>1710-1-16</td>
<td>60AP:30HN:10MPD</td>
<td>1.0 3.0 45 0.05</td>
<td>10.8 1.95</td>
<td>30-70</td>
<td>50.0</td>
<td>Flexible, resilient, good homogeneous cellular structure</td>
</tr>
<tr>
<td>1710-1-17</td>
<td>60AP:30HN:10MPD</td>
<td>1.0 3.0 55 0.15</td>
<td>10.8 1.95</td>
<td>30-70</td>
<td>50.0</td>
<td>Flexible, resilient, good homogeneous cellular structure</td>
</tr>
<tr>
<td>1710-1-18</td>
<td>60AP:30HN:10MPD</td>
<td>1.0 3.0 40 0.30</td>
<td>10.8 1.95</td>
<td>30-70</td>
<td>50.0</td>
<td>Flexible, resilient, good homogeneous cellular structure</td>
</tr>
<tr>
<td>1710-1-19</td>
<td>60AP:30HN:10MPD</td>
<td>1.0 3.0 45 0.05</td>
<td>10.8 1.95</td>
<td>30-70</td>
<td>50.0</td>
<td>Flexible, resilient, good homogeneous cellular structure</td>
</tr>
<tr>
<td>1710-1-22</td>
<td>60AP:30HN:10MPD</td>
<td>1.0 3.0 40 0.30</td>
<td>10.8 1.95</td>
<td>30-70</td>
<td>50.0</td>
<td>Flexible, resilient, good homogeneous cellular structure</td>
</tr>
</tbody>
</table>

Figure 4. Properties of Advanced Aromatic Terpolyimide Systems
<table>
<thead>
<tr>
<th>No.</th>
<th>Density</th>
<th>95% Compression Set</th>
<th>Foil Character.</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td>100% 25°C</td>
<td>25°C 30 Min. Recovery</td>
</tr>
<tr>
<td>123-1</td>
<td>Propyl</td>
<td>1.44</td>
<td>23.0</td>
</tr>
<tr>
<td>123-1-2</td>
<td>Butyl</td>
<td>1.52</td>
<td>21.1</td>
</tr>
<tr>
<td>123-1-3</td>
<td>Hexa</td>
<td>1.67</td>
<td>20.0</td>
</tr>
<tr>
<td>123-1-4</td>
<td>Octa</td>
<td>0.941</td>
<td>15.1</td>
</tr>
<tr>
<td>123-1-5</td>
<td>Dodeca</td>
<td>1.63</td>
<td>25.9</td>
</tr>
<tr>
<td>123-1-6</td>
<td>Hexa</td>
<td>1.71</td>
<td>17.8</td>
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<tr>
<td>123-1-7</td>
<td>Dodeca</td>
<td>0.887</td>
<td>13.0</td>
</tr>
<tr>
<td>123-1-8</td>
<td>Hexa</td>
<td>1.48</td>
<td>22.4</td>
</tr>
<tr>
<td>123-1-9</td>
<td>Dodeca</td>
<td>1.32</td>
<td>24.0</td>
</tr>
<tr>
<td>123-1-10</td>
<td>Propyl</td>
<td>1.48</td>
<td>23.7</td>
</tr>
<tr>
<td>123-1-11</td>
<td>Butyl</td>
<td>1.40</td>
<td>23.3</td>
</tr>
<tr>
<td>123-1-12</td>
<td>Hexa</td>
<td>1.33</td>
<td>21.2</td>
</tr>
<tr>
<td>123-1-13</td>
<td>Dodeca</td>
<td>0.778</td>
<td>13.5</td>
</tr>
<tr>
<td>123-1-14</td>
<td>Propyl</td>
<td>1.33</td>
<td>21.2</td>
</tr>
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<td>123-1-15</td>
<td>Butyl</td>
<td>0.915</td>
<td>13.0</td>
</tr>
<tr>
<td>123-1-16</td>
<td>Hexa</td>
<td>1.44</td>
<td>25.0</td>
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<tr>
<td>123-1-17</td>
<td>Octa</td>
<td>0.841</td>
<td>10.5</td>
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<tr>
<td>123-1-18</td>
<td>Dodeca</td>
<td>0.565</td>
<td>0.84</td>
</tr>
<tr>
<td>123-1-19</td>
<td>Propyl</td>
<td>1.15</td>
<td>18.3</td>
</tr>
<tr>
<td>123-1-20</td>
<td>Butyl</td>
<td>0.399</td>
<td>6.36</td>
</tr>
</tbody>
</table>

Figure 5. Aliphatic Terpolyimide Foam Precursors and Foam Characteristics (1702-1 Resin System)
<table>
<thead>
<tr>
<th>Foam Resin Number</th>
<th>Composition</th>
<th>Molar Ratio</th>
<th>Concentration of Surfactant AE-2 (%)</th>
<th>% Loss After 30 Minutes Recovery</th>
<th>Type of Foam</th>
</tr>
</thead>
<tbody>
<tr>
<td>1702-1-62</td>
<td>BTDA:2,6DAP:MDA</td>
<td>1:0.3:0.7</td>
<td>0.0125</td>
<td>40.0</td>
<td>Fine, homogeneous cellular structure</td>
</tr>
<tr>
<td>1701-1-5</td>
<td>BTDA:2,6DAP:MDA</td>
<td>1:0.4:0.6</td>
<td>0.0125</td>
<td>19.6</td>
<td>Medium-large homogeneous cellular structure</td>
</tr>
<tr>
<td>1701-1-7</td>
<td>BTDA:2,6DAP:MDA</td>
<td>1:0.42:0.58</td>
<td>0.0125</td>
<td>12.1</td>
<td>Reticulated foam with medium size cellular structure</td>
</tr>
<tr>
<td>1701-1-8</td>
<td>BTDA:2,6DAP:MDA</td>
<td>1:0.44:0.56</td>
<td>0.0125</td>
<td>—</td>
<td>Highly reticulated foam with large and weak cellular structure</td>
</tr>
<tr>
<td>1702-2-10</td>
<td>BTDA:2,6DAP:MDA</td>
<td>1:0.5:0.5</td>
<td>0.0125</td>
<td>—</td>
<td>Highly reticulated foam with chopped strands like cell structure. Poor - hollow foam</td>
</tr>
</tbody>
</table>

**Figure 6.** Flexible, Resilient, Polyimide Foams: Effect of Solar Concentration Of 2,6DAP On Compression Set Lo-s Values
Figure 7. Flexible, Resilient Polyimide Foams: Effect of Surfactant Concentration (AS-2) On Compression Set Loss

<table>
<thead>
<tr>
<th>Power Output (kW)</th>
<th>Time to Foam (Seconds)</th>
<th>Total Foaming Cycle (Seconds)</th>
<th>Foaming Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5</td>
<td>120</td>
<td>240</td>
<td>fine cellular structure</td>
</tr>
<tr>
<td>5.0</td>
<td>75</td>
<td>210</td>
<td>fine cellular structure</td>
</tr>
<tr>
<td>10</td>
<td>60</td>
<td>180</td>
<td>large portion of foam, cured in microwave</td>
</tr>
</tbody>
</table>

Figure 8. Foaming Behavior of 1702-1 Precursors At Various Power Outputs
Figure 10. Effect of Preheat Temperature (2 Min.) on Compression Set Loss of 1701-1 Polyimide Foams Modified With 0.015 Percent AS-2
Figure 11. Effect of Preheat Time on Compression Set Loss (250°F) of 1701-1 Polyimide Foams
Figure 12. Effect of Foaming Time on Compression Set Loss of Aliphatic Terpolyimide System (1720-1)
Figure 13. Effect of Curing Temperature on 90% Compression Set Values of Foams Derived from 1701-1 Precursors Modified With 0.015% and 0.02% AS-2 Respectively
LOW DENSITY WALL PANELS

TASKS

- OPTIMIZATION OF RIGID POLYIMIDE FOAM PANELS
- LOW DENSITY CORE, HIGH DENSITY SKIN PANELS
- OPTIMIZATION OF LOW DENSITY CORE TECHNOLOGY

OBJECTIVES

- DEVELOPMENT OF TECHNIQUES TO PRODUCE FINAL WALL PANEL CONFIGURATIONS IN A ONE-STEP PROCESS WITHOUT THE USE OF ADHESIVES.
- FABRICATION OF WALL PANELS HAVING LOW DENSITY CENTERS AND HIGH DENSITY EDGES TO MEET DIRECT SCREW WITHDRAWAL REQUIREMENTS.

Figure 14. Low Density Wall Panels
Figure 15. Fabrication of Rigid Low Density Panels From Powder Polyimide Precursors in a One-Step Microwave Process
HIGH STRENGTH FLOOR PANELS

TASKS

. OPTIMIZATION OF RIGID POLYIMIDE FOAM PANELS

. NEW CONFIGURATIONS

OBJECTIVES

. DEVELOPMENT OF PANEL CORE MEETING HIGH TRAFFIC AREA REQUIREMENTS

DEVELOPMENT OF RIGID PANELS WITH VARIABLE DENSITY CHARACTERISTICS

Figure 16. High Strength Floor Panels

THERMAL ACOUSTICAL INSULATION

TASKS

. ADVANCED POLYIMIDE SYNTHESIS

FOAMING STUDIES

COATING PROCESS FOR GLASS FIBERS AND MATS

OBJECTIVES

OPTIMIZATION OF THE BURNTHROUGH PROPERTIES OF THE FOAMS

Figure 17. Thermal Acoustical Insulation
Figure 18. 1702 Polyimide Resin Spray Coated & Foamed on Owens-Corning PF 105-700 Fiberglass 20 x 20 CM Effect of Loading on Burn Test.
Figure 19. Effect of Fillers on Burnthrough Characteristics of Polyimide Foam: Left 1702-1, 1.0% AS-2, 20% Glass Strands 3% Microballoons

FUTURE PLANS

- Development of large scale foam processing.
- Fabrication of shaped flexible foams by the use of closed or open molds.
- Optimization of the microwave process to produce rigid panels with densified skins.
- Development of thermal acoustical materials meeting the burnthrough requirements
- Selection of one or more candidates for each of the products under study.

Figure 20. Future Plans
GLOBAL ENCLOSURE FIRE MODELING
WITH APPLICATIONS
FIREMEN

FIRE MODELING AND SCALING METHODS
510-56-05

Jay Wm. Stuart
OUTLINE

- Brief review of LERC limiting energy release criteria
- Application of LERC to JSC/Boeing ignition source full-scale tests
- Application of LERC to JSC/DACFIR math-model validation-tests
LIMITING ENERGY RELEASE CRITERIA-LERC

**Flame Spread Rate**
\[ \dot{Q}_S = (\dot{Q}/A) b v t \quad \text{(Linear)} \]

**Fuel Surface Limit**
\[ \dot{Q}_f = 2500 A_f \quad \text{(Gasoline)} \]

**Ventilation Limit**
\[ \dot{Q}_V = 1580 A H^{1/2} \]

**Enclosure Volume**
\[ t_e = \frac{58 V_e}{\dot{Q}} \]

**Fuel Load**
\[ t_e = \frac{M_f \Delta H}{\dot{Q}} \]

**Combined Criteria**
\[ t_e = \frac{Q_e}{2\dot{Q}} \left(1 - \frac{\dot{Q}_V}{\dot{Q}}\right)^{-1} \]

\[ Q_e = 58 V_e \]

**Units:**
- Kilowatts
- Meters
- Kilograms
- Minutes
DATA VARIABILITY
LARGE FUEL PAN / LARGE CABIN VOLUME

FUEL - TURBOJET A
TEST VENT. \( \Delta Q, \% \)

- 16 16.4 kg/min. -34.1
- 17 17.1 +30.9

\( Q_f \) (2x2 ft)

\( V = 16.4 \text{ kg/min} = 475 \text{ cfm} \)

\( Q_e/2 \)
\((V = 112 \text{ m}^3)\)

\( Q_i \)
\((F_V = 4.5 \text{ ft})\)

ENERGY RELEASE RATE \( k_e \)

BURN TIME MINUTES

[Graph and diagram with data points and labels]
DATA VARIABILITY
LARGE FUEL PAN / LARGE CABIN VOLUME

FUEL - TURBOJET A

\[ Q_v = 60.2 \text{ kg/m}^3 = 2000 \text{ cfm} \]

ENERGY RELEASE RATE

\[ Q_f \]

(2x2 ft)

WT LOSS DATA

FUSELAGE SECTION

LINER

VENT FORE & AFT

\[ Q_{a/2} \]

(V = 112 m$^3$)

\[ Q_f \]

(F$_v$ = 4.5 in)

BURN TIME

MINUTES

ENERGY RELEASE RATE

Kw

10

100

1000

10

100

1000

0.1

1.0

10

100
CABIN SEAT LERC

ENERGY RELEASE RATE $K_w$

IGNITION FUEL POOL
SEAT
BACK BOTTOM

BURN TIME MINUTES

VENT FORE & AFT
FUSELAGE SECTION
LINER
TOTAL FUEL POOL
SEAT BACK BOTTOM

TOTAL

$Q_f$
$Q_t$
$Q_v$
CONCLUSIONS

- A complete LERC application to the JSC/Boeing tests verifies the fuel load criterion as the consistent limiting constraint.

- The variability of magnitude and form of the results of repeated tests with and without small variations in parameters emphasizes the significance of the local flow, species-concentration, and heat-transfer distributions.

- Weight-loss measurements of recent JSC tests show consistent results with prior methods; fuel load constrained.
ENCLOSURE FIRE DYNAMICS MODEL
505-08-25

Josette Bellan

March 1, 1979
ENCLOSURE FIRE DYNAMICS MODEL

Plan of the Presentation

1) Practical situation. Why a fire dynamics model?
2) Difficulties in establishing a model.
3) Brief review of enclosure-fire models available.
4) Our approximation of the practical situation.
5) Our model.
It has been shown by global modeling of experimental data that fire can be limited in its propagation by two factors:

- Lack of O₂ (ventilation, enclosure volume)
- Lack of fuel (fuel load, fuel surface)
IT HAS ADDITIONALLY BEEN OBSERVED THAT:

- THE OUTCOME OF THE FIRE IS STRONGLY INFLUENCED BY VENTILATION PATTERNS

- THE OUTCOME OF THE FIRE IS STRONGLY INFLUENCED BY THE LOCATION OF THE FIRE

- THERE IS A STRONG TEMPERATURE CHANGE NOT ONLY IN THE HORIZONTAL, BUT ALSO IN THE VERTICAL DIRECTION DUE TO AIR BUOYANCY

- SURFACES, OTHER THAN THOSE BURNING, ARE FURTHER IGNITED DUE TO RADIATION AND/OR CONVECTION FROM THE EXISTING FIRE

GLOBAL MODELING CANNOT PREDICT THESE LATTER FIRE CHARACTERISTICS

A DETAILED ANALYTICAL MODEL IS NEEDED
DIFFICULTIES IN ESTABLISHING A MATHEMATICAL MODEL DESCRIBING FIRE IN AIRCRAFT

1) GEOMETRICAL ASPECTS
2) TURBULENT ASPECTS
   Lack of data to indicate levels of turbulence transport (cm²/sec)
3) COMBUSTION ASPECTS
   Lack of knowledge on the detailed chemical mechanism. Lack of data (E and A) to approximate those mechanisms by a one step reaction.
4) DESCRIPTION OF THE COUPLING BETWEEN COMBUSTION AND TURBULENCE
5) RADIATION ASPECTS
   View factors, emissivities, gas phase absorptance and transmittance
6) BOUNDARY CONDITIONS AND WALL EFFECTS
   Difficult to correctly approximate both wall and core phenomena within reasonable constraints (money, time, computer time)
7) LACK OF THERMOPHYSICAL AND THERMOCHEMICAL CONSTANTS FOR VARIOUS MATERIALS THAT ARE USED IN AIRCRAFT.
# Review of Enclosure - Fire Models

<table>
<thead>
<tr>
<th>Field of Study</th>
<th>Conservation Equations</th>
<th>Boundary Conditions</th>
<th>Predicted Quantities</th>
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<tbody>
<tr>
<td>EFDM</td>
<td>F (2-D)</td>
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<tr>
<td>Notre Dame</td>
<td>F (2-D)</td>
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<tr>
<td>Arc Donnell</td>
<td>Z (2I)</td>
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<td>Dayton</td>
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<td>ITIRI</td>
<td>Z (2I)</td>
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<td>NBS</td>
<td>Z (2I)</td>
<td></td>
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</tr>
<tr>
<td>Harvard</td>
<td>Z (2I)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Field or Zone:**
  - EFDM
  - Notre Dame
  - Arc Donnell
  - Dayton
  - ITIRI
  - NBS
  - Harvard

- **Conservation Equations:**
  - Mass
  - Momentum
  - Energy
  - Gas Species
  - Smoke

- **Boundary Conditions:**
  - Radiation
  - Plume Model
  - Specific Data Required

- **Predicted Quantities:**
  - E = Empirical Input Required
  - P = Predicted
  - SE = Semi-Empirical
  - NA = Not Applicable
  - UK = Unknown

- **Additional Notes:**
  - No-Slip Velocity, Heat Transfer to Surfaces, Gasification of Fuel
  - Various Fundamental Physical Properties, Species and Soot Concentration
  - Rates and Times Governing Transition States, Heat Release, Species Evolution, Flame Spread
  - Combustion Efficiency
  - SOF Concentration, Gasification Temps, Stoichiometry
APPROXIMATION OF THE PRACTICAL SITUATION

MATHEMATICAL MODELING INCLUDES:
- WRITING THE CONSERVATION EQUATIONS FOR TURBULENT FLOW
- MODELING THE COMBUSTION TERMS IN THESE EQUATIONS
- MODELING THE RADIATION TERMS IN THESE EQUATIONS
- WRITING THE BOUNDARY CONDITIONS FOR A GIVEN SITUATION
- WRITING THE INITIAL CONDITIONS FOR A GIVEN SITUATION
- FINDING THE VALUE OF THE RELEVANT BASIC CONSTANTS THAT ARE RELATED TO MATERIAL PROPERTIES
THE CONSERVATION EQUATIONS
(1 of 3)

MASS
\[
\frac{\partial \rho}{\partial t} + \frac{\partial (\rho u)}{\partial x} + \frac{\partial (\rho v)}{\partial y} = 0
\]

transient term
convective terms

x-MOMENTUM COMPONENT
\[
\rho \frac{\partial u}{\partial t} + \rho u \frac{\partial u}{\partial x} + \rho v \frac{\partial u}{\partial y} = -\frac{\partial p}{\partial x} - g \rho \sin \theta + \text{pressure change term}
\]

transient term
convective terms
buoyancy term

\[
\frac{\partial}{\partial x} \left[ \left( -\frac{2}{3} \mu_T \right) \left( \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} \right) \right] + 2 \frac{\partial}{\partial x} \left( \mu_T \frac{\partial u}{\partial x} \right) + \frac{\partial}{\partial y} \left[ \mu_T \left( \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} \right) \right]
\]

viscous stress terms (turbulent)
THE CONSERVATION EQUATIONS
(2 of 3)

**y-MOMENTUM COMPONENT**

\[
\rho \frac{\partial v}{\partial t} + \rho u \frac{\partial v}{\partial x} + \rho v \frac{\partial v}{\partial y} = - \frac{\partial p}{\partial y} - g \rho \cos \theta
\]

- transient term
- convective terms
- pressure change term
- buoyancy term

\[
+ \frac{\partial}{\partial x} \left[ \mu_T \left( \frac{\partial v}{\partial x} + \frac{\partial u}{\partial y} \right) \right] + \frac{\partial}{\partial y} \left[ \left( -\frac{2}{3} \mu_T \right) \left( \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} \right) \right] + 2 \frac{\partial}{\partial y} \left[ \mu_T \frac{\partial v}{\partial y} \right]
\]

viscous stress terms
(turbulent)

**SPECIES**

\[
\rho \frac{\partial Y_i}{\partial t} + \rho u \frac{\partial Y_i}{\partial x} + \rho v \frac{\partial Y_i}{\partial y} = \frac{\partial}{\partial x} \left( D_{xT} \frac{\partial Y_i}{\partial x} \right) + \frac{\partial}{\partial y} \left( D_{yT} \frac{\partial Y_i}{\partial y} \right) + \omega_i
\]

- transient term
- convective terms
- diffusive terms (turbulent)
- source or sink term

\[ i = \text{fuel, oxygen, nitrogen, water, carbon dioxide.} \]
THE CONSERVATION EQUATIONS
(3 of 3)

ENERGY

\[
\rho C_p \frac{\partial T}{\partial t} + \rho u C_p \frac{\partial T}{\partial x} + \rho v C_p \frac{\partial T}{\partial y} = \frac{\partial p}{\partial t} + \frac{\partial}{\partial x} \left( k x_T \frac{\partial T}{\partial x} \right) + \frac{\partial}{\partial y} \left( k y_T \frac{\partial T}{\partial y} \right)
\]

\[\text{transient term} \quad \text{convective terms} \quad \text{pressure change term}\]

\[-g \rho v + \dot{Q}_\rho + \dot{R}_{\text{net}}\]

work source of heat due to combustion radiation term

STATE

\[p = \rho RT \quad \text{with} \quad R = R_u \sum_{i} \frac{Y_i}{W_i}\]
MODELING OF COMBUSTION

\[ \text{C}_n \text{H}_m + (n + \frac{m}{4}) \text{O}_2 \rightarrow n \text{CO}_2 + \frac{m}{2} \text{H}_2\text{O} \]

\[ \dot{\omega}_F = c_1 \dot{\omega}_O_2 \quad \text{with} \quad c_1 = \frac{w_F}{w_{O_2}} \frac{1}{n + \frac{m}{4}} \]

\[ \dot{\omega}_{\text{CO}_2} = -c_2 \dot{\omega}_O_2 \quad \text{with} \quad c_2 = \frac{w_{\text{CO}_2}}{w_{O_2}} \frac{n}{n + \frac{m}{4}} \]

\[ \dot{\omega}_{\text{H}_2\text{O}} = -c_3 \dot{\omega}_O_2 \quad \text{with} \quad c_3 = \frac{w_{\text{H}_2\text{O}}}{w_{O_2}} \frac{m/2}{n + \frac{m}{4}} \]

\[ \dot{\omega}_{O_2} = \frac{d}{dt} \left[ \frac{w_{O_2}}{w_{O_2}} \right] = -k_f \frac{1}{w_F} \gamma_F \gamma_{O_2} \rho^2 \quad \text{with} \quad k_f = A e^{-E/RT} \]

\[ Q = \frac{1}{\rho} \left( c_1 h_F^0 - c_2 h_{\text{CO}_2}^0 - c_3 h_{\text{H}_2\text{O}}^0 \right) \left( -\dot{\omega}_{O_2} \right) \]
BOUNDARY CONDITIONS

WALLS (INERT)

\( u = 0 \), \( v = 0 \)

\( \frac{\partial Y_j}{\partial n} = 0 \); \( \overrightarrow{n} \) is the direction perpendicular to the wall

thin wall assumption

\( \delta_w \rho_w C_w \frac{\partial T_w}{\partial t} = k_g \frac{\partial T}{\partial n} + \dot{q}_{\text{net}} + \frac{\partial}{\partial s} \left( k_s \frac{\partial T_w}{\partial s} \right) \); \( \overrightarrow{s} \) is the direction along the wall;

ENTRANCE \( (x = 0, \ y_1 < y < y_2) \)

\( A \overrightarrow{\Omega} = \dot{m}_{\text{air}} \) (forced ventilation)

\( v = 0 \)

\( \rho, T, Y_F, Y_{O_2}, Y_{N_2}, Y_{CO_2}, Y_{H_2O} \) given
BOUNDARY CONDITIONS (Cont'd)

EXIT (x = L : \( y \prec y \prec y_c' \))

\( \rho, u, v, Y_F, Y_{O_2}, Y_{N_2}, Y_{CO_2}, Y_{H_2O}, T \) are found by forward extrapolation.

POOL SURFACE (y = 0, \( x_1 < x < x_2' \))

\( u = 0 \)

\( \rho v \ Y_F - \rho D \ \frac{\partial Y_F}{\partial y} = \dot{M}_F \)

\( \rho v \ Y_i - \rho D \ \frac{\partial Y_i}{\partial y} = 0 \quad i = O_2, N_2, CO_2, H_2O \)

\( \dot{M}_F = \alpha \ \rho_{atm} \ \frac{1}{R} \ \left( \frac{1}{T_b} - \frac{1}{T} \right) \ Y_F \ \frac{1}{w_F} \ \sum \frac{1}{w_i} \ \left( \frac{w_F}{2\pi RT_i} \right)^{1/2} \)

thin wall assumption

\( \delta \ \rho \ \frac{\partial T}{\partial y} = \gamma \ \frac{\partial T}{\partial y} + \dot{c}_{net} - \dot{M}_F \ \frac{L}{c} \)
PRESENT AND FUTURE WORK

1) **Model the radiation terms**
   - in the energy equation
   - in the boundary conditions

2) **Encode the equations**
   - select a computation scheme
   - transform the equations from a differential to a finite form
   - develop a computer code

3) **Ascertain thermophysical and thermochemical constants that are relevant to aircraft materials**

4) **Characterize the flow conditions in aircraft (levels of turbulence) using available experimental data**
LARGE-SCALE POOL FIRE TEST RECOMMENDATIONS

FIREMEN
FIRE MODELING AND SCALING METHODS
510-56-05

C. Perry Bankston

February 26, 1979
IMPORTANT ASPECTS
OF
EXTERNAL POOL FIRES

- Heat transfer
  convective
  radiative

- Flame characteristics
  burning rates
  flame shape, size
  turbulence
  wind effects

- Plume characteristics
  entrainment
  turbulence
  wind effects

- Unsteady phenomena
  fire oscillations
  fire whirls
OBJECTIVES

- Determine heat flux to surfaces as a function of pool size
  - Convective heat flux
  - Radiative heat flux
- Obtain information that can be compared with theoretical model for radiative flux in the 'near field'
- Predict radiative heat flux for arbitrary pool size
MEASUREMENTS AND INSTRUMENTATION:

- HEAT FLUX: CALORIMETERS, RADIOMETERS
- TEMPERATURE: THERMOCOUPLES
- FLAME SIZE, SHAPE: PHOTOGRAPHY
- WEATHER ENVIRONMENT
VERTICAL POSITIONING OF NEAR-FIELD HEAT
FLUX CALORIMETERS AND THERMOCOUPLES

<table>
<thead>
<tr>
<th>5 FT. POOL</th>
<th>10 FT. POOL</th>
<th>15 FT. POOL</th>
</tr>
</thead>
<tbody>
<tr>
<td>L = 15'</td>
<td>L = 25'</td>
<td>L = 30'</td>
</tr>
</tbody>
</table>

- 6 12.5' = 5/2W
- 5 10' = 2W
- 4 7.5' = 3/2W
- 3 5' = W
- 2 2.5' = W/2
- 1 0' = 0W

- 6 25' = 5/2W
- 5 20' = 2W
- 4 15' = 3/2W
- 3 10' = W
- 2 5' = W/2
- 1 0' = 0W

○ REPRESENTS THERMOCOUPLE LOCATION
■ REPRESENTS HEAT FLUX CALORIMETER LOCATION
LOCATION OF POOL FIRE INSTRUMENTATION
(PLAN VIEW)

- Prevailing wind

- In-the-flame calorimeter and thermocouple (directed down at height of 0.6L)
- Near-field calorimeter/thermocouple tree
- Far-field radiometers
MEASUREMENTS AND INSTRUMENTATION:

- 10 FT. X 10 FT. PANELS

- HEAT FLUX: CALORIMETERS
- TEMPERATURE (GAS, SURFACES): THERMOCOUPLES
- FLAME SIZE, SHAPE: PHOTOGRAPHY
- WEATHER ENVIRONMENT
10 FT X 10 FT PANEL INSTRUMENTATION

- ○ - THERMOCOUPLE
- □ - HEAT FLUX CALORIMETER

DIAGRAM LEGEND:
- TC - THERMOCOUPLE
- INSULATION
- DECORATIVE FILM
- OUTER SKIN
- INNER SKIN
POOL FIRE FLAME HEAT BALANCE

ENERGY IN:
\[ \dot{M}_F h_F + \dot{M}_E h_E + \beta \dot{M}_F \Delta H \]
FUEL ENTRAINED COMBUSTION AIR
EQUALS

ENERGY OUT:
\[ \dot{Q}_{R \text{TOT}} + \dot{M}_p h_p \]
RADIATION COMBUSTION PRODUCTS
RADIATIVE HEAT TRANSFER MODELING

- HOMOGENEOUS, ISOTHERMAL ASSUMPTION
  INPUT: FLAME SHAPE
  FLAME TEMPERATURE
  EMISSIVITY
  OUTPUT: SPATIAL DISTRIBUTION OF RADIATION IN THE NEAR-FIELD

- NON-HOMOGENEOUS CASE (DETAILED FLAME MODEL)
  INPUT: THERMOCHEMICAL PROPERTIES
  BOUNDARY CONDITIONS
  OUTPUT: FLAME SHAPE, TEMPERATURE, EMISSIVITY
  BURNING RATE, ETC
  SPATIAL DISTRIBUTION OF RADIATION IN THE NEAR FIELD
FUSELAGE VENTILATION
UNDER WIND CONDITIONS

FIRE MODELING AND SCALING METHODS
510-56-05

Jay Wm. Stuart
OBJECTIVES

• Determine realistic fuselage ventilation rates for post-crash fires and full-scale fire tests

• Find effects on wind-about-fuselage ventilation rate of various parameters
  Fuselage size & shape
  Fuselage orientation & proximity to ground
  Fuselage-openings size & location
  Wind speed & direction
FLUID MECHANICS OF FUSELAGE VENTILATION

FROM MASS CONTINUITY AND ASSUMING $d\rho = 0$

SOLVE $U_1A_1 = U_2A_2$ OR $A_1C_1\sqrt{\frac{2(p_1 - p_i)}{\rho}} = A_2C_2\sqrt{\frac{2(p_1 - p_2)}{\rho}}$

LETTING $C_p = \frac{\rho}{q}$, $q = \frac{\rho}{2} U_{\infty, n}^2$

VOLUMETRIC RATE $Q = C_1A_1 U_{\infty, n} \sqrt{C_{p_1} - \left[ C_{p_1} + C_{p_2} \left( \frac{A_2C_2}{A_1C_1} \right)^2 \right] / \left[ \frac{A_2C_2}{A_1C_1} + 1 \right]}$

INTERIOR VENTILATION SPEED $\bar{U} = Q/A_f$

129
PRESSURE DISTRIBUTIONS FOR FLOWS AROUND INFINITE CIRCULAR CYLINDERS

SINGLE CYLINDER

INVISCID

80° 180° 280°

- ∞ - ∞ - ∞

TYP

C_p = 1.0

SINGLE CYLINDER IN STREAM PARALLEL TO WALL WITH BOUNDARY LAYER \( R_{De} = 4.25 \times 10^4 \)

G/D = 0.4

UNIFORM STREAM

VISCID

G

\[ \frac{G}{D} = 0.4 \]

\[ C_p \]

UNIFORM SHEAR \( K = 0.6 \)

INVISCID

\[ \frac{G}{D} = 0.4 \]

DEGREES

-60 -30 0 30 60 90 120 150 180-150-120-90
REFERENCES FOR PRESSURE DISTRIBUTIONS
AROUND CIRCULAR CYLINDERS


VENTILATION PERFORMANCE COMPARISON
FIXED OPENINGS

\[ A_1 = 2 \text{ m}^2; C_1 = 0.8 \]
\[ A_2/A_1 = 1.0 = C_2/C_1 \]

\[ U_{ref} = 10 \text{ mph} \]
\[ R_{De} = 4.8 \times 10^4 \]
\[ R_D = 1.23 \times 10^6 \]

\[ \frac{Q}{D} \text{ FIXED OPENING } \frac{C_p(a)}{C_p(a)} \]

\[ C_p = 1.0, C_p_2 \]

\[ \theta = 0.1 \degree \text{ WAKE } C_p_1(a) = C_{p,w} \]
VENTILATION PERFORMANCE
IN 2-DIM. FLOW
OVER FUSELAGE

STAGNATION POINT

Q in cfs

Degrees

C1 = C2 = 0.6
U_m = 10mph
A_r = 2m²
R_D = 4.8E4
R_D = 1.23E6

C_p = 1.0
C_p = 2.0
C_p = 1.0
C_p = 0.96
G/D = 0.4
CONDUCT JSC FULL-SCALE FIRE TESTS TO VALIDATE THE ESTIMATES OF FUSELAGE VENTILATION OF THIS ANALYSIS

For the **real** wind-about-fuselage conditions experimentally determine ventilation rates applicable to post-crash fires & full-scale fire tests

- Wind speed & direction
- Full-scale Reynolds numbers
- Fuselage shape
- Fuselage orientation & proximity to ground
- Fuselage-openings size & location
- Fire-convection induced speed or circulation
FIRE RESISTANT AIRCRAFT
SEAT PROGRAM

PRESENTED
AT
JOINT NASA/INDUSTRY STEERING GROUP UPDATE
AND REVIEW MEETING    March 1 & 2, 1979

Larry L. Fewell
Project Director
FIRE RESISTANT AIRCRAFT SEAT MATERIALS

LARRY L. FEMMEL
PROJECT DIRECTOR
TYPICAL SEATING ARRANGEMENT ON A WIDE BODY JET
PHASE I MATERIAL TEST PROGRAM

MATHEMATICAL MODEL

WEIGHT DENSITY

DIMENSIONS

FAA BURN TESTS
165°F AGED
SPECIMENS
AND NON-AGED

FAA NBS SMOKE
165°F AGED
SPECIMENS
AND NON-AGED

FAA MOD
BURN TESTS
(MATERIALS
THAT MELT)

LOI

TGA

PILL TEST
IGNITION
AND
FLASH PER
J1579

SCREENING
TESTS

TEXTILES

• DYEABILITY AND
• COLORFASTNESS
• ABRASION
• TENSILE
• ELONGATION
• CORROSION
• CLEANABILITY
• SHRINKAGE

THERMOFORMABLE
PLASTICS

• HEAT DEFORMATION
• FORMABILITY
• STRESS CRACKING
• IMPACT GARDNER
TESTER
• TENSILE
• TENSILE MOD
• MACHINABILITY
• COLORFASTNESS

DEFLECTION

ANIMAL
TEST
TOXICITY

HHR AND
FLASH FIRE

DATA
BASE

ADVANCED
TESTS

PERFORMANCE
TESTS

SCREEN NO FURTHER TESTING

SCREEN NO FURTHER TESTING

SCREEN NO FURTHER TESTING

FOAMS

• STEAM AUTOCLAVE
• INDENTATION LOAD
DEFLECTION (ILD)
• COMPRESSION SET
• TEAR
• LOAD VERSUS
DEFLECTION

TEXTILES

• DYEABILITY AND
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DEFLECTION

ANIMAL
TEST
TOXICITY

HHR AND
FLASH FIRE

DATA
BASE
**Phase II**

- Fire Scenarios in Wide Body Jet Aircraft
- Construction of candidate seats (specifying each component) (seat manufacturer)
- Full Scale Testing of Prototype Seats in Cabin Fire Simulator
- Determination of desirable Fire-Resistivity Levels
- Inservice Evaluation
- Materials & Design Options

**Phase III**

- Co-ordination of CFS data with laboratory tests (singular & multilayered)
  - Fire-Resistivity Level
  - Processability
  - Manufacturing Feasibility of Availability
  - Value decisions (based on tradeoffs)
  - Acceptance Criteria for Fire Safety and Performance
  - Manufacturing Specifications
<table>
<thead>
<tr>
<th>MATERIAL NUMBER</th>
<th>PRODUCT NUMBER</th>
<th>MATERIAL DESCRIPTION</th>
<th>TRADE NAME</th>
<th>SUPPLIER</th>
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<tbody>
<tr>
<td>100</td>
<td>ST7193-29</td>
<td>100% NYLON, AIRGARD TREATED 11.4-12.6 OZ/YD² LANDSCAPE FABRIC</td>
<td>LANDSCAPE</td>
<td>COLLINS &amp; AIKMAN CORP.</td>
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<tr>
<td>101</td>
<td>20787</td>
<td>52.5% KERMEL/47.5% WOOL 277 gm/m²</td>
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<td>H. LELEIVRE, PARIS</td>
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<tr>
<td>102</td>
<td>OL618</td>
<td>100% COTTON DOUBLEKNIT 10 ± 5% OZ/YD² (LI SPEC 33)</td>
<td>-</td>
<td>LANGENTHAL INTERNATIONAL CORP.</td>
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<tr>
<td>103</td>
<td>69-407</td>
<td>100% NOMEX 8.4-8.7 OZ/YD² TULSA (DRAPERY FABRIC)</td>
<td>TULSA</td>
<td>COLLINS &amp; AIKMAN CORP.</td>
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<tr>
<td>*104</td>
<td>ST7427-112</td>
<td>90% WOOL/10% NYLON FABRIC 12.2 TO 14.0 OZ/YD² SUN ECLIPSE</td>
<td>SUN ECLIPSE</td>
<td>COLLINS &amp; AIKMAN CORP.</td>
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<tr>
<td>105</td>
<td>7979</td>
<td>50% KYNOL/50% NOMEX 10.7 OZ/YD² FABRIC</td>
<td>&quot;NO BURN&quot; FABRIC</td>
<td>COLLINS &amp; AIKMAN CORP.</td>
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<tr>
<td>106</td>
<td>NYLON GOLD</td>
<td>NYLON GOLD/VONAR 3 NEOPRENE FOAM BACKING</td>
<td>-</td>
<td>DUPONT DE NEMOURS</td>
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<tr>
<td>107</td>
<td>URETHANE COATED NYLON</td>
<td>URETHANE ELASTOMER COATED NYLON FABRIC</td>
<td>-</td>
<td>REEVES BROTHERS</td>
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<tr>
<td>108</td>
<td>NO. 300 COTTON KNIT FABRIC</td>
<td>COTTON KNIT FABRIC, COLOR 23 JASMIN</td>
<td>-</td>
<td>LANGENTHAL INTERNATIONAL CORP.</td>
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<tr>
<td>109</td>
<td>NO. 340 COTTON KNIT FABRIC</td>
<td>COTTON KNIT FABRIC SQUARE KNIT</td>
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<td>LANGENTHAL INTERNATIONAL CORP.</td>
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<tr>
<td>110</td>
<td>2069</td>
<td>KERMEL, 39%WOOL 61%, COLOR 2 ROUX FABRIC 576 g/m²</td>
<td>-</td>
<td>H. LELEIVRE, PARIS</td>
</tr>
<tr>
<td>MATERIAL NUMBER</td>
<td>PRODUCT NUMBER</td>
<td>MATERIAL DESCRIPTION</td>
<td>TRADE NAME</td>
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<td>200</td>
<td>NO. 24</td>
<td>100% KYNOL FABRIC TWILL WEAVE</td>
<td>KYNOL</td>
<td>AMERICAN KYNOL, INC</td>
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<tr>
<td>201</td>
<td>NO. 1110</td>
<td>70% KYNOL/30% NOMEX PERMANENT PRESS FINISH 6.2 OZ/YD²</td>
<td>KYNOL</td>
<td>AMERICAN KYNOL, INC</td>
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<tr>
<td>202</td>
<td>NO. 1090</td>
<td>70% KYNOL 30% NOMEX 4.6 OZ/YD² WITH PERMANENT PRESS FINISH</td>
<td>KYNOL</td>
<td>AMERICAN KYNOL INC</td>
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<tr>
<td>203</td>
<td>B-104S</td>
<td>100% KYNOL BATTING ON POLYESTER SCRIM-NEEDLE PUNCH</td>
<td>KYNOL</td>
<td>AMERICAN KYNOL, INC</td>
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<tr>
<td>204</td>
<td>40-9010-1</td>
<td>PBI FABRIC NATURAL UNSTABILIZED 5.1 OZ/YD² 2 x 1 TWILL</td>
<td>-</td>
<td>CELANESE FIBERS MARKETING CO.</td>
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<tr>
<td>205</td>
<td>40-4010-1</td>
<td>PBI BATTING 4 OZ/YD² NATURAL UNSTABILIZED FROM STAPLE</td>
<td>-</td>
<td>CELANESE FIBERS MARKETING CO.</td>
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<tr>
<td>206</td>
<td>35-4020-1</td>
<td>BLACK BATTING 4 OZ/YD² (PROPRIETARY)</td>
<td>-</td>
<td>CELANESE FIBERS MARKETING CO.</td>
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<tr>
<td>207</td>
<td>KYNOL ON REMAY SCRIM BATTING</td>
<td>REMAY SPUN BONDED POLYESTER FABRIC NEEDLED WITH 100% KYNOL FIBER .8 OZ/YD²</td>
<td>&quot;FLAMEOUT&quot;</td>
<td>DAN RIVER, INC</td>
</tr>
<tr>
<td>208</td>
<td>NEOPRENE FOAM</td>
<td>1/16 IN. NEOPRENE FOAM WITH 1.2 OZ/YD² COTTON SCRIM</td>
<td>VONAR NO. 1 INTERLINER</td>
<td>DUPONT DE NEMOURS</td>
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<tr>
<td>209</td>
<td>NEOPRENE FOAM</td>
<td>2/16 IN. NEOPRENE FOAM WITH 1.2 OZ/YD² COTTON SCRIM</td>
<td>VONAR NO. 2 INTERLINER</td>
<td>DUPONT DE NEMOURS</td>
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<tr>
<td>210</td>
<td>NEOPRENE FOAM</td>
<td>3/16 IN. NEOPRENE FOAM WITH 1.2 OZ/YD² COTTON SCRIM</td>
<td>VONAR NO. 3 INTERLINER</td>
<td>DUPONT DE NEMOURS</td>
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<tr>
<td>211</td>
<td>NYLON GOLD 1902</td>
<td>SEE NO. 108</td>
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<tr>
<td>212</td>
<td>UPHOLSTERY FABRIC</td>
<td>DURETTE UPHOLSTERY FABRIC</td>
<td>DURETTE</td>
<td>FIRE SAFE PRODUCTS</td>
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<tr>
<td>213</td>
<td>SE5559</td>
<td>ELASTOMER, SILICONE RUBBER S.G. 1.33</td>
<td>-</td>
<td>GENERAL ELECTRIC (WATERFORD, NY)</td>
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<tr>
<td>214</td>
<td>NOMEX III</td>
<td>ARAMID FABRIC</td>
<td>NOMEX III</td>
<td>DUPONT DE NEMOURS &amp; CO.</td>
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<tr>
<td>215</td>
<td>KERMEL</td>
<td>KERMEL FABRIC 250 gm/m² AMIDE-IMIDE</td>
<td>KERMEL</td>
<td>RHODIA, INC</td>
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<td>216</td>
<td>400-11</td>
<td>DURETTE BATTLING</td>
<td>DURETTE</td>
<td>FIRE SAFE PRODUCTS</td>
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<tr>
<td>217</td>
<td>400-6</td>
<td>DURETTE DUCK 4.4 OZ/YD²</td>
<td>DURETTE</td>
<td>FIRE SAFE PRODUCTS</td>
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<td>218</td>
<td>410-13</td>
<td>DURETTE DUCK BLACK</td>
<td>DURETTE</td>
<td>FIRE SAFE PRODUCTS</td>
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<td>219</td>
<td>400-37</td>
<td>DURETTE TWILL</td>
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<td>FIRE SAFE PRODUCTS</td>
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### Candidate Materials Tested (Cont'd)

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<tr>
<td>220</td>
<td>35-4025</td>
<td>PREOXIDIZED BATTING 400-8</td>
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<td>CELANESSE FIBER MARKETING CO</td>
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<tr>
<td>221</td>
<td>S470</td>
<td>NOMEX III DUAL FABRIC, NATURAL 7.5 OZ/YD²</td>
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<td>SOUTHERN MILLS, INC SENOIA, GA</td>
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<tr>
<td>222</td>
<td>40-9031-2</td>
<td>WOVEN PBI FABRIC HEAT STABILIZED 4.2 OZ/YD², 2 x 1 TWILL MADE FROM THERMALLY STABILIZED PBI YARN</td>
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<td>CELANESSE FIBER MARKETING CO</td>
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<td>PRODUCT NUMBER</td>
<td>MATERIAL DESCRIPTION</td>
<td>TRADE NAME</td>
<td>SUPPLIER</td>
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<td>---------------------------------------------------------------------</td>
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<tr>
<td>300</td>
<td>FG215</td>
<td>GLASS FIBER BLOCK CUSHION EDGE GRAIN BLOCKING OF GLASS FIBERS</td>
<td>-</td>
<td>EXPANDED RUBBER AND PLASTICS CORP.</td>
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<tr>
<td>301</td>
<td>R-207080</td>
<td>APN PHOSPHAZENE OPEN CELL FOAM 0.14 g/cc</td>
<td>APN FOAM</td>
<td>FIRESTONE TIRE &amp; RUBBER CO.</td>
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<tr>
<td>302</td>
<td>9907-13</td>
<td>URETHANE FOAM, FLEXIBLE</td>
<td>HYPOL</td>
<td>W. R. GRACE &amp; CO.</td>
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<tr>
<td>303</td>
<td>EXP1408</td>
<td>SILICONE RUBBER SPONGE 11 LB/FT³</td>
<td>-</td>
<td>KIRKHILL RUBBER COMPANY</td>
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<tr>
<td>304</td>
<td>14183-B</td>
<td>SILICONE RUBBER SPONGE 11.8 LB/FT³</td>
<td>MOSITES</td>
<td>MOSITES RUBBER CO., INC.</td>
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<tr>
<td>305</td>
<td>NO. 510</td>
<td>SILICONE RUBBER SPONGE 0.21 gm/cc</td>
<td>-</td>
<td>SILICONE ENGINEERING LTD. ENGLAND</td>
</tr>
<tr>
<td>306</td>
<td>H-45C</td>
<td>URETHANE FOAM 0.03 gm/cc</td>
<td>-</td>
<td>E. R. CARPENTER CO., INC</td>
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<tr>
<td>307</td>
<td>HL1-7-77</td>
<td>NEOPRENE FOAM, OPEN CELL</td>
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<td>TOYAD CORP.</td>
</tr>
<tr>
<td>308</td>
<td>KAYLON FIRM</td>
<td>NEOPRENE FOAM, OPEN CELL</td>
<td>KAYLON</td>
<td>UNIROYAL INC.</td>
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<tr>
<td>309</td>
<td>9FR6188</td>
<td>SILICONE SPONGE 9.4 LB/FT³</td>
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<td>KIRKHILL RUBBER</td>
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<tr>
<td>MATERIAL NUMBER</td>
<td>PRODUCT NUMBER</td>
<td>MATERIAL DESCRIPTION</td>
<td>TRADE NAME</td>
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<tr>
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<tr>
<td>310</td>
<td>LS FORMULA T121B</td>
<td>NEOPRENE FOAM 7.5 PCF</td>
<td></td>
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<tr>
<td>311</td>
<td>3-6581/9508/1-KYNOL</td>
<td>SILICONE FOAM CEMENTED TO KYNOL FABRIC WITH 96-091 ADHESIVE 102 OZ/YD²</td>
<td></td>
<td>DOW CORNING</td>
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<tr>
<td>312</td>
<td>TOSIL SILICONE</td>
<td>SILICONE FOAM FROM JAPAN (GE AFFILIATE) 18.5 LB/FT³</td>
<td>TOSIL</td>
<td>GE</td>
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<tr>
<td>313</td>
<td>E-300</td>
<td>URETHANE FOAM, FLAME RETARDED 3.1 PCF</td>
<td>EMPIRE</td>
<td>CREST-FOAM CORP. MOONACHIE, NJ</td>
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<tr>
<td>314</td>
<td>T-47FR</td>
<td>URETHANE FOAM</td>
<td>TEMPER FOAM</td>
<td>EDMONT WILSON REP CMS ASSOCIATES, CMS INC. ENCINO, CA</td>
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<tr>
<td>315</td>
<td>200</td>
<td>POLYIMIDE FOAM NAS 9-15050</td>
<td></td>
<td>SOLAR TURBINES INTERNATIONAL SAN DIEGO, CA VIA NASA HOUSTON</td>
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<td>MATERIAL NUMBER</td>
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<td>MATERIAL DESCRIPTION</td>
<td>TRADE NAME</td>
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<tr>
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<td>400</td>
<td>170</td>
<td>SILICONE ADHESIVE</td>
<td>SYLGRD</td>
<td>DOW CORNING CORP.</td>
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<td>401</td>
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<td>CARPET MOD ACRYLIC</td>
<td>BRUNS WALL</td>
<td>BRUNS WALL CORP.</td>
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<td>402</td>
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<td>POLYPHENYLENESULPHONE PPS THERMOPLASTIC</td>
<td>RADEL</td>
<td>UNION CARBIDE</td>
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<tr>
<td>403</td>
<td>57-1825</td>
<td>ABS THERMOPLASTIC SHEET</td>
<td>ROYALTE</td>
<td>UNIROYAL</td>
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<tr>
<td>404</td>
<td>10052-72D</td>
<td>RIGID URETHANE FOAM</td>
<td>HYPOL</td>
<td>W. R. GRACE &amp; CO.</td>
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<td>405</td>
<td>685</td>
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<td>KWIKSTIK</td>
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<tr>
<td>406</td>
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<tr>
<td>407</td>
<td>2332 N/F</td>
<td>ADHESIVE (NEOPRENE)</td>
<td>CON BOND</td>
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<td></td>
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<td>408</td>
<td>EC 4715</td>
<td>ADHESIVE</td>
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<td>3M ADHESIVE, COATING &amp; SEALERS DIVISION</td>
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<td>409</td>
<td>RTV 133</td>
<td>ADHESIVE, SILICONE</td>
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<td>GENERAL ELECTRIC WATERFORD, NY</td>
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# MATERIALS DROPPED AS CANDIDATES

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>PROBLEM</th>
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<tbody>
<tr>
<td>(200, 201, 202) KYNOL FABRICS</td>
<td>POOR WEAVE AND COLORFASTNESS</td>
</tr>
<tr>
<td>(102) COTTON KNIT</td>
<td>COLOR AVAILABILITY</td>
</tr>
<tr>
<td>(103) NOMEX FABRIC</td>
<td>COLORFASTNESS</td>
</tr>
<tr>
<td>(106) VONAR-BACKED NYLON</td>
<td>COLORFASTNESS</td>
</tr>
<tr>
<td>(107) URETHANE-COATED NYLON</td>
<td>NO LONGER AVAILABLE</td>
</tr>
<tr>
<td>(204, 205) PBI FABRICS</td>
<td>LOW STRENGTH (TEAR)</td>
</tr>
<tr>
<td>(206) BLACK BATTING 40-4010-1</td>
<td>THERMAL SHRINKAGE</td>
</tr>
<tr>
<td>(207) KYNOL NEEDLED TO REMAY</td>
<td>EXTREME TOXICITY</td>
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<tr>
<td>(212) DURETTE UPHOLSTERY FABRIC</td>
<td>THERMAL WEIGHT LOSS</td>
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<tr>
<td>(215) KERMEL FABRIC</td>
<td>COLORFASTNESS</td>
</tr>
<tr>
<td>(301) R-207080 APN PHOSPHAZENE FOAM</td>
<td>THERMAL SHRINKAGE</td>
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<tr>
<td>(302) HYPO1 URETHANE FOAM</td>
<td>LOW STRENGTH</td>
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<tr>
<td>(304) 14183-B SILICONE FOAM</td>
<td>HIGH SMOKE GENERATION</td>
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<tr>
<td>(305) 510 SILICONE FOAM</td>
<td>HIGH HEAT RELEASE</td>
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<tr>
<td>(308) KOYOL NEOPRENE FOAM</td>
<td>FAILS BURN TEST</td>
</tr>
<tr>
<td></td>
<td>FAILS SMOKE GENERATION</td>
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</table>
FUTURE SEAT COMPONENTS

- DECORATIVE FABRIC COVER
- SLIP SHEET (TOPPER)
- FIRE BLOCKING LAYER
- CUSHION REINFORCEMENT
- CUSHIONING LAYER

NOTE: SOME COMPONENTS MAY NOT BE INCLUDED IN ALL DESIGNS
DECORATIVE FABRIC COVER

KEY REQUIREMENTS — *COLORFAST
COLOR AVAILABILITY
RESISTANCE TO IGNITION
LOW FLAME SPREAD
WEARABILITY
LOW TOXICITY
LOW SMOKE GENERATION

CANDIDATE MATERIALS —

(100) ST-7793-29 AIRGARD-TREATED NYLON C&A
(101) 20787 KERMEL 47 PERCENT WOOL
53 PERCENT BLEND LELEVERE

*GO-NO GO REQUIREMENT
SLIP SHEET

KEY REQUIREMENTS — LOW WEAR
LOW FRICTION
IGNITION RESISTANCE
LOW FLAME SPREAD
LOW TOXICITY
LOW THERMAL SHRINKAGE

CANDIDATE MATERIALS —

(214) NOMEX III ARAMID 254 g/m² DUPONT
(217) 400-6 DURETTE DUCK FIRE SAFE PROD.
FIRE BLOCKING LAYER

KEY REQUIREMENTS — BURN RESISTANCE
   LOW SMOKE GENERATION
   LOW HEAT RELEASE
   LOW FLAME SPREAD
   LOW TOXICITY
   LOW THERMAL CONDUCTIVITY
   GOOD CHAR FORMATION

CANDIDATE MATERIALS

(203)  13-104  KYNOL NEEDLE PUNCH BATTING  AMER KYNOL INC.
(210)  VONAR NO. 3  NEOPRENE FOAM INTERLINER  DUPONT
(214)  NOMEX III  NOMEX FABRIC  DUPONT
(216)  400-11  DUREJTE BATTING  FIRE SAFE PROD.
CUSHIONING REINFORCEMENT

KEY REQUIREMENT — WEAR RESISTANCE
  BURN RESISTANCE
  COMPATIBILITY
  (i.e., ADHESION STIFFNESS CEMENTABILITY)
  LOW TOXICITY

CANDIDATE MATERIALS —

(213)  SE-559  SILICONE ELASTOMER  GE
(214)  NOMEX III  FABRIC  DUPONT
(217)  400-6  DURETTE DUCK FABRIC  FIRE SAFE PROD.
CUSHIONING

KEY REQUIREMENTS — LOW TOTAL HEAT RELEASE
LOW TOXICITY
LOW SMOKE GENERATION
LOW FLASH PROPENSITY
(LOW WEIGHT LOSS)
• BREAKDOWN RESISTANCE

CANDIDATE MATERIALS —

<table>
<thead>
<tr>
<th>(301)</th>
<th>HL 1-7-77 NEOPRENE FOAM</th>
<th>TOYAD CORP.</th>
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<tbody>
<tr>
<td>(300)</td>
<td>FG 215 GLASS FIBER BLOCK</td>
<td>EXPANDED RUBBER</td>
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<tr>
<td>(303)</td>
<td>EXP 1408 SILICONE FOAM</td>
<td>KIRKHILL RUBBER</td>
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<tr>
<td>*</td>
<td>LS NEOPRENE FOAM</td>
<td>TOYAD CORP.</td>
</tr>
<tr>
<td>*</td>
<td>9 FR 618 SILICONE FOAM</td>
<td>KIRKHILL RUBBER</td>
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*NOT SCREENED TO DATE
HEAT RELEASE RATE TESTING

PART 1          STANDARD CUSHION LAYER OF GLASS
                BLOCKING WITH VARIOUS UPPER LAYERS

PART 2          SELECTED UPPER LAYERS FROM PART 1
                WITH VARIOUS CUSHION LAYERS
TYPICAL MULTIPLE LAYER TEST SPECIMEN

HRR SAMPLE HOLDER
CERAMIC BACKUP PLATE
CUSHION
ADHESIVE
REINFORCEMENT
FIRE BLOCKING LAYER
ADHESIVE
SLIP COVER
DECORATOR FABRIC (FRONT)
STAINLESS STEEL SAMPLE HOLDER 10 x 10 in.

TC NO. 2
TC NO. 1
TC NO. 3

HRR SAMPLE HOLDER
INJECTION ROD

ASSEMBLY DIRECTION INTO HOLDER
CEMENTED

FOLDED CORNERS AND EDGES
OSU HEAT RELEASE APPARATUS

SAMPLE

SMOKE DETECTOR

RADIANT PANEL

TO GAS SUPPLY

AIR DISTRIBUTION PLATE

PILOT FLAME

AIR INLET
<table>
<thead>
<tr>
<th>SAMPLE NO.</th>
<th>SAMPLE FORM</th>
<th>GENERIC NAME</th>
<th>MATERIAL DESCRIPTION</th>
<th>MATERIAL DENSITY</th>
<th>FUNCTION IN MULTILAYER ASSEMBLY</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>FABRIC</td>
<td>AMIDE-IMIDE</td>
<td>52.5% KERTEL; 47% WOOL</td>
<td>290 g/m²</td>
<td>DECORATIVE COVERING LAYER</td>
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<tr>
<td></td>
<td></td>
<td>WOOL</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>FABRIC</td>
<td>WOOL/AMIDE</td>
<td>90% WOOL; 10% NYLON</td>
<td>457 g/m²</td>
<td>DECORATIVE COVERING LAYER</td>
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<tr>
<td>3</td>
<td>FABRIC</td>
<td>ARAMID</td>
<td>NOMEX III</td>
<td>254 g/m²</td>
<td>SLIP COVER CUSHION REINFORCEMENT</td>
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<td>4</td>
<td>BATTING</td>
<td>CHLORINATED</td>
<td>DURETTE</td>
<td></td>
<td>FIRE BLOCKING LAYER</td>
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<td></td>
<td></td>
<td>ARAMID</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>FOAM</td>
<td>POLYCHLORO-</td>
<td>0.175 cm THICK POLYCHLOROPRENE</td>
<td>954 g/m³</td>
<td>FIRE BLOCKING LAYER</td>
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<td>PRENE WITH</td>
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<td></td>
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<td>COTTON SCRIM</td>
<td></td>
<td></td>
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<td>6</td>
<td>DUCK</td>
<td>CHLORINATED</td>
<td>DURETTE</td>
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<td>CUSHION REINFORCEMENT</td>
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<td></td>
<td></td>
<td>ARAMID</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>7</td>
<td>FABRIC</td>
<td>NOVOLOID</td>
<td>KYNOL</td>
<td>213 g/m²</td>
<td>FIRE BLOCKING LAYER</td>
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### MATERIALS UTILIZED IN THE CONSTRUCTION OF MULTILAYER ASSEMBLIES (CONTINUED)

<table>
<thead>
<tr>
<th>SAMPLE NO.</th>
<th>SAMPLE FORM</th>
<th>GENERIC NAME</th>
<th>MATERIAL DESCRIPTION</th>
<th>MATERIAL DENSITY</th>
<th>FUNCTION IN MULTILAYER ASSEMBLY</th>
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<tbody>
<tr>
<td>8</td>
<td>FABRIC</td>
<td>SILICONE ELASTOMER ON GLASS FABRIC</td>
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<td>CUSHION REINFORCEMENT</td>
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<tr>
<td>9</td>
<td>ADHESIVE</td>
<td>R2332 NF</td>
<td>–</td>
<td>CEMENT</td>
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<tr>
<td>10</td>
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<td>RTV 133</td>
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<tr>
<td>11</td>
<td>FOAM</td>
<td>URETHANE</td>
<td>POLYURETHANE FOAM</td>
<td>0.20 g/cm³</td>
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<td>GLASS</td>
<td>GLASS FIBER BLOCK CUSHION</td>
<td>0.03 g/cm³</td>
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<td>13</td>
<td>FOAM</td>
<td>IMIDE</td>
<td>POLYIMIDE FOAM</td>
<td>0.06 g/cm³</td>
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<tr>
<td>14</td>
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<td>SILICONE RUBBER SPONGE</td>
<td>0.19 g/cm³</td>
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<td>POLYCHLOROPRENE</td>
<td>LOW SMOKE NEOPRENE FOAM</td>
<td>0.14 g/cm³</td>
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# Multilayer Materials with Glass Fiber Block Backing

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<th>ML Specimen No.</th>
<th>Adhesive</th>
<th>Fire Block</th>
<th>Reinforcement</th>
<th>Adhesive</th>
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<td>R2332NF</td>
<td>B1045 KYNOL</td>
<td>NOMEX III</td>
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<td>B1045 KYNOL</td>
<td>DURETTE DUCK 400-6</td>
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<td>3</td>
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<td>B1045 KYNOL</td>
<td>SE5559 ON GLASS FABRIC</td>
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<td>4</td>
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<td>VONAR #3</td>
<td>SE5559 ON GLASS FABRIC</td>
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<td>7</td>
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<td>DURETTE BATT 400-11</td>
<td>SE5559 ON GLASS FABRIC</td>
<td>RTV 133</td>
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<tr>
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<td>DURETTE BATT 400-11</td>
<td>NOMEX III</td>
<td>SAME</td>
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<tr>
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<td>DURETTE BATT 400-11</td>
<td>DURETTE DUCK 400-6</td>
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All ML specimen contained 52.5% kermel wool blend with Nomex III slip cover.
### MULTILAYER MATERIALS WITH POLYMERIC FOAM BACKING

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<th>ADHESIVE</th>
<th>FIRE BLOCK</th>
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<td>DURETTE BATT 400-11</td>
<td>NOMEX III</td>
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<td>SILICONE FOAM</td>
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<td>14</td>
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<td>AL S-NEOPRENE FOAM</td>
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<td>NOMEX III</td>
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<tr>
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<tr>
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<tr>
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<td>DURETTE BATT 400-11</td>
<td>PBI 40-9031-2</td>
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<td>AL S-NEOPRENE FOAM</td>
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ML SPECIMENS CONTAINED 52.6% KERMEL/47.5% WOOL BLEND WITH NOMEX III SLIP COVER.
• ML SPECIMEN CONTAINED 90% WOOL/10% NYLON BLEND WITH FLAME RETARDED COTTON MUSLIN SLIP COVER.
○ ML SPECIMEN CONTAINED 52.5% KERMEL/47.5% WOOL BLEND WITH FLAME RETARDED COTTON MUSLIN SLIP COVER.
ⁿ ML SPECIMEN CONTAINED 52.5% KERMEL/47.5% WOOL BLEND WITH NO SLIP COVER.
○ ML SPECIMEN CONTAINED FLAME RETARDED COTTON MUSLIN SLIP COVER.
# THERMAL FLUX — HEAT RELEASE

<table>
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<tr>
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<td>1.5</td>
<td>3.5</td>
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<tr>
<td>1.5 MIN</td>
<td>25.7</td>
<td>99</td>
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<tr>
<td>3 MIN</td>
<td>57.6</td>
<td>212</td>
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<tr>
<td>5 MIN</td>
<td>72.1</td>
<td>319</td>
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<td>10 MIN</td>
<td>—</td>
<td>438</td>
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<td>SPECIMEN NO.</td>
<td>20</td>
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<table>
<thead>
<tr>
<th>DESCRIPTION OF LAYERS</th>
<th>DECORATIVE COTTON</th>
<th>SLIP COVER COTTON</th>
<th>FIRE BLOCK</th>
<th>REINFORCEMENT</th>
<th>CUSHION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(104)</td>
<td>(104)</td>
<td>(101)</td>
<td>(101)</td>
<td>(306)</td>
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<td>COTTON</td>
<td>COTTON</td>
<td>(214)</td>
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<td>(306)</td>
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<td>(216)</td>
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<td>(310)</td>
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<td></td>
<td></td>
<td>(222)</td>
<td>(214)</td>
<td>(310)</td>
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</tbody>
</table>
COMPARISON OF HEAT RELEASE FROM ADVANCED AND BASELINE MATERIALS

- BASELINE MATERIALS
- ADVANCED FIRE RESISTANT MATERIALS

HEAT FLUX @ 1.5 W/cm²
HEAT FLUX @ 3.5 W/cm²

HEAT RELEASE (kW/m² X 100)

TIME, min

0 2 4 6 10
FIRE SOURCE DETERMINATION
AIRCRAFT SURVEY
# AIRLINE TRASH DATA

<table>
<thead>
<tr>
<th>AIRPLANE: DC-10</th>
<th>DATE: 2-23-78</th>
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</table>

<table>
<thead>
<tr>
<th>BAG 1</th>
<th>BAG 2</th>
<th>BAG 3</th>
<th>BAG 4</th>
<th>BAG 5</th>
<th>BAG 6</th>
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<tr>
<td>AIRCRAFT ORIGIN</td>
<td>CHICAGO</td>
<td>CHICAGO</td>
<td>CHICAGO</td>
<td>LONDON</td>
<td>LONDON</td>
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<tr>
<td>SEAT NO./LOCATION</td>
<td>22K AND L/COACH</td>
<td>5K/FIRST CLASS</td>
<td>12D/COACH</td>
<td>UNKNOWN</td>
<td>12B/COACH</td>
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<tr>
<td>LOCATION RELATIVE TO SEAT</td>
<td>ON FLOOR UNDER AND BEHIND SEAT</td>
<td>ON FLOOR BEHIND SEAT</td>
<td>ON FLOOR UNDER SEAT</td>
<td>UNKNOWN</td>
<td>IN POCKET ON BACK OF SEAT</td>
</tr>
<tr>
<td>ITEMS COLLECTED</td>
<td>NEWSPAPER – 7 SECTIONS AND ADS</td>
<td>HEADPHONE BAG – PACKS</td>
<td>2 NEWSPAPERS – ONE WITH SIX SECTIONS</td>
<td>2 NEWSPAPERS</td>
<td>2 HEADSET BAGS</td>
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<tr>
<td></td>
<td></td>
<td>NEWSPAPER</td>
<td></td>
<td></td>
<td>1 AIRSICK BAG</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1 NAPKIN (COCKTAIL SIZE)</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>1 AIRLINE MAG</td>
</tr>
<tr>
<td>WEIGHT OF ITEMS</td>
<td>1.44 POUNDS</td>
<td>1.50 POUNDS</td>
<td>2.15 POUNDS</td>
<td>1.52 POUNDS</td>
<td>0.45 POUNDS</td>
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</table>

**AVERAGE WEIGHT OF ITEMS:**
1.385 POUNDS
SUMMARY

- NEWSPAPER WAS THE MOST PREVALENT ITEM ON AIRCRAFT.

- THE MANNER IN WHICH NEWSPAPER WAS FOLDED AND PLACED WILL DETERMINE THE MAGNITUDE AND DURATION OF THE FIRE.

- THE NEWSPAPER IN THE FORM OF A TENT WILL GIVE A REPEATABLE FIRE.

- ONE AND ONE-HALF POUNDS OF NEWSPAPER WILL PROVIDE A MORE SEVERE FIRE THAN 3 POUNDS.
A REVIEW OF BOEING INTERIOR MATERIALS AND FIRE TEST METHODS DEVELOPMENT PROGRAMS

FEBRUARY 1979
TOTAL MATERIALS SYSTEMS REQUIREMENTS

- Cleanability
- Strength
- Durability
- Maintainability
- Repairability
- Customization
- Reproducibility
- Installation factors

- Fire Safety
  - Flammability
  - Smoke
  - Toxicity

- Design
  - Strength
  - Weight
  - Appearance
  - Comfort
  - Configuration
  - Architecture

- Manufacturing
  - Material availability
  - Facilities and equipment
  - Process complexity
  - Repeatability
  - Installation factors
  - Cost
GOVERNMENT AND INDUSTRY PROGRAMS
PRESENTED AT FAA HEARING NOVEMBER 1977

- C133 FIRE TESTS
- TOXICITY AND SMOKE TESTS
- COMBUSTION PRODUCTS
- ANIMAL EXPOSURE
- FIRE MODELING
- COMBINED HAZARD INDEX
- FIRE MANAGEMENT SMOKE VISIBILITY

GOVERNMENT/INDUSTRY TECHNICAL GROUP

NAFEC
CAMI
UDRI
McD
LAC

FAR's

FAA

NASA

MATERIAL SUPPLIERS

BOEING

LOCKHEED

McDONNELL DOUGLAS

DOT/TSC

AIA

ACTIVE PARTICIPATION

FLAMMABILITY DATA BANK

COORDINATED PROGRAM DEVELOP TECHNOLOGY

MATERIALS DEVELOPMENT
TOXICITY TESTS
FULL-SCALE TESTS

DATA

DEVELOP PLANS MONITOR PROGRESS DEVELOP TECHNOLOGY

SANDWICH PANELS LAVATORY HARDENING FIRE TEST METHODS

CARGO TESTS LAVATORY FIRE TESTS SEAT MATERIALS

MATERIALS DEVELOPMENT FIRE TEST METHODS

THERMOPLASTICS

1971 PAGE IS OF POOR QUALITY
INTERIOR MATERIALS DEVELOPMENT

- NPRM's
- Boeing Goals
  - Materials Develop.
  - Selection of Materials
- Test Methods Develop.
  - Selection of Test Methods
- Establishment of Materials Requirements - BCAC Policy -
  - BMS Specifications
  - Design Requirements & Objectives Doc.
- New Airplane Design
A NEW TEST METHODOLOGY CONCEPT

CABIN ENVIRONMENT TOLERANCE LIMITS

- TEMPERATURE
- VISIBILITY
- TOXIC GAS CONCENTRATION
- OTHERS

FUTURE MATERIALS
SELECTION BASED ON PREDICTED MATERIAL PERFORMANCE IN CABIN FIRE ENVIRONMENT

MATERIALS' PROPERTIES

- HEAT RELEASE
- SMOKE RELEASE
- TOXIC GAS EMISSION
- FLAMMABILITY
- OTHERS

INTEGRATED LABORATORY TEST

GOAL

CORRELATION
POTENTIAL DECREASE IN FIRE HAZARD LEVEL
-POST CRASH FIRE-

CURRENT MATL'S
CARGO & BAGGAGE
JET FUEL

REVISED MATL'S
CARGO & BAGGAGE
JET FUEL

CONTRIBUTORS TO THE
CABIN FIRE HAZARD LEVEL

POTENTIAL HAZARD LEVEL REDUCTION

CABIN FIRE HAZARD LEVEL
(TEMPERATURE, SMOKE, GASES)
BOEING FIRE TEST METHODOLOGY DEVELOPMENT

HAZARD LIMIT DATA DEVELOPED BY FAA, NASA, INDUSTRY AND ACADEMIC COMMUNITY

TOTAL HAZARD LEVEL ASSESSMENT

CONTROL MATERIAL PROPERTIES FOR AIRPLANE USE

FAA/McD-D CHI INPUT ON MATERIAL USE, EXTENT, ETC.

BOEING FULL SCALE MATERIAL TESTING

HEAT, SMOKE AND TOXICANT RELEASE

PREDICTED DESIGN FIRE RESULTS IN AN AIRPLANE PASSENGER CABIN

BOEING LAB FIRE TESTING OF MATERIALS

DEVELOP CORRELATION

MATERIAL FIRE TEST PROPERTIES

DESIGN FIRE SOURCE HEAT, SMOKE AND TOXICANT RELEASE

NASA-JSC/BOEING FULL SCALE FIRE SOURCE TESTS

TEST METHODOLOGY

BOEING DEVELOPMENT PROJECT

OTHER DEVELOPMENT PROJECT
FIRE TEST METHODOLOGY PROGRESS

- ESTABLISHED DESIGN FIRE SOURCES (NASA CONTRACT NAS9-15168)

- SELECTED OSU APPARATUS AS POSSIBLE TEST METHOD FOR PREDICTION OF HEAT AND SMOKE IN AN AIRPLANE FIRE (REQUIRES FURTHER REFINEMENT)

- NEED MAJOR EFFORTS IN TOXICANT MEASUREMENT AND TOXICITY LIMITS
# FLAMMABILITY, SMOKE AND TOXICITY GOALS

**FLAMMABILITY**
- FAR 25.583 AMMENDMENT 25-32
- FLAME SPREAD INDEX MAXIMUM 25
  - APPARATUS-ASTM E 162

**SMOKE**

4.0 MINUTES

NBS CHAMBER, 2.5 WATTS CM\(^2\) HEAT FLUX:
- LARGE AREA, \(D_S\) MAXIMUM 50
- SMALL AREA, \(D_S\) MAXIMUM 200

**TOXICITY**

<table>
<thead>
<tr>
<th>GAS EMISSION (PPM)</th>
<th>CO</th>
<th>HCN</th>
<th>HF</th>
<th>HCl</th>
<th>SO(_2)</th>
<th>NO(_2)</th>
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<tbody>
<tr>
<td>TIME</td>
<td></td>
<td></td>
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<td>3000</td>
<td>100</td>
<td>150</td>
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<tr>
<td>4.0 MINUTES</td>
<td>3500</td>
<td>150</td>
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<td>500</td>
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<tr>
<td>_scope - major materials systems</td>
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<td>--------------------------------</td>
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<td></td>
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<tr>
<td>Decorative Sandwich Panels</td>
<td>Flexible Ducts and Tubing</td>
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<td>Compression Molded FG.</td>
<td>Fiberglass Laminates</td>
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<td>Transparencies</td>
<td>Carpets and Underlays</td>
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<td>Insulation and Coverings</td>
<td>Rigid Foams</td>
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<td>Sandwich Air Ducts</td>
<td>Cargo Lining</td>
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<td>HIGH PRESSURE LAMINATES</td>
<td>SEALANTS AND ADHESIVES</td>
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<tr>
<td>------------------------</td>
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<td>COATED FABRICS</td>
<td>ADVANCED COMPOSITES</td>
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<td>DRAPERY FABRICS</td>
<td>FLOOR PANELS</td>
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<td>FLOOR COVERINGS</td>
<td>POTTING COMPOUNDS</td>
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<td>ELASTOMERS</td>
<td>METAL LAMINATES</td>
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### NEW MATERIAL/CURRENT MATERIAL COMPARISONS (EXAMPLES)

<table>
<thead>
<tr>
<th>FLEXIBLE DUCTING</th>
<th>SMOKE RELEASE</th>
<th>FLAME SPREAD &amp; HEAT RELEASE</th>
<th>TOXICITY</th>
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<td>NBS</td>
<td>OSU</td>
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<td>37</td>
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<td>COMPRESSION MOLDED F.G.</td>
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<td>F.G. LAMINATES</td>
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<tr>
<td>CURRENT</td>
<td>46.0</td>
<td>49.4</td>
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<tr>
<td>NEW</td>
<td>0.2</td>
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<td>SIDEWALLS</td>
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<td>CURRENT (LAMINATED/</td>
<td>70-90</td>
<td>82-90</td>
<td>17-25</td>
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<td>SANDWICH PANELS)</td>
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<tr>
<td>NEW (SANDWICH PANELS)</td>
<td>49</td>
<td>47</td>
<td>PLANNED</td>
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</tbody>
</table>

1. GOAL ≤ 50 @ 2.5 W/CM² @ 4 MIN.  
2. 5 W/CM² @ 90 SEC.  
3. POST-CRASH @ 90 SEC.  
4. GOAL ≤ 25  
5. 5 W/CM² @ 215 SEC.  
6. POST-CRASH @ 215 SEC.  
7. @ 2.5 W/CM² @ 4 MIN.

* SIMULATED FULL SCALE TEST DATA
PROGRESS IN MATERIALS DEVELOPMENT

- DEVELOPMENT OF MATERIALS TO GOALS IS NEARLY COMPLETE

- MAJOR LINING MATERIALS EVALUATED TO DATE FOR NEW AIRPLANE USE SHOW FIRE PROPERTY IMPROVEMENTS IN FULL SCALE AND LABORATORY TESTS

- THE REDUCTION IN AIRPLANE FIRE HAZARD IF NEW MATERIALS ARE USED IS NOT DEFINED
GOVERNMENTAL REGULATIONS

• RATIONAL BASIS NOT YET ESTABLISHED FOR ADDITIONAL REGULATION

• CORRELATION OF LAB TEST TO AIRPLANE FIRE RESULTS APPEARS POSSIBLE - BUT METHODOLOGY YEARS AWAY

• REDUCTION IN MATERIAL CONTRIBUTION TO AIRPLANE FIRE HAZARD CAN NOT BE APPRAISED YET
SAFER COMMITTEE SHOULD BE MADE OPERATIVE

- Coordination on national level needed for research and regulations

- SAFER STEERING GROUP MEMBERS MUST BE TECHNICALLY KNOWLEDGEABLE AND CAPABLE OF COMMITTING RESEARCH
FIREMEN PROGRAM

STATUS REPORT

R.A. Anderson and G.A. Johnson
Boeing Commercial Airplane Company
March 1979
DEVELOPMENT AND FABRICATION PROGRAMS
DEVELOPMENT PROGRAM
OVERVIEW

- BEGAN IN 1975
- FOUR PHASE PARTICIPATION
- INTERIOR SANDWICH PANEL DEVELOPMENT
OBJECTIVES

- IMPROVE
  - FLAMMABILITY
  - SMOKE EMISSION
  - TOXICITY

- MAINTAIN
  - MECHANICAL PROPERTIES
  - AESTHETICS
  - SERVICEABILITY
  - COSTS
• PHASE I – BASELINE LAVATORY BURN
  (NAS2 – 8700)

• PHASE II – RESIN SYSTEM DEVELOPMENT
  (NAS2 – 8700)

• PHASE III – DECORATIVE FILM DEVELOPMENT
  (NAS2 – 8700)

• PHASE IV – DECORATIVE INK DEVELOPMENT
  (NAS2 – 9864)
PHASE I – BASELINE LAVATORY BURN

- 747 LAVATORY MODULE
- TEST CONDITIONS
  - 30 MINUTES
  - DOOR CLOSED
  - 10 POUNDS TRASH
- INFLIGHT, UNOBSERVED FIRE
RESULTS

- FIRE CONTAINED
- CURRENT CONSTRUCTION ADEQUATE
- NASA CR-152074
PHASE II - RESIN SYSTEM DEVELOPMENT

PREPREG

PREPREG

PREPREG

PREPREG

PREPREG
APPROACH

• CANDIDATE RESIN SYSTEMS
  • BASELINE EPOXY
  • BISMALEIMIDE
  • PHENOLIC
  • POLYIMIDE

• TESTING MATRIX
  • FLAMMABILITY, SMOKE, AND TOXICITY
  • MECHANICALS AND AESTHETICS
RESULTS

• PHENOLICS
  • FLAMMABILITY, SMOKE, AND TOXICITY
  • MATERIAL AND FABRICATION COSTS
  • LABORATORY SCALE TESTING
• PROBLEM
  • AESTHETICS
• NASA CR-152120
DECORATIVE LAMINATE MAKEUP

EMBOSSING MEDIA
PVF (CLEAR)
ACRYLIC INK
PVF (WHITE)
PHENOLIC PREPREG
PHASE III – DECORATIVE FILM DEVELOPMENT

TOP FILM

SUBSTRATE FILM

TOP FILM

SUBSTRATE FILM

SUBSTRATE FILM

TOP FILM
OVERVIEW

- NUMEROUS CANDIDATES
- TESTING MATRIX
  - FLAMMABILITY, SMOKE, AND TOXICITY
  - MECHANICALS AND AESTHETICS
APPROACH

- SINGLE FILM
- SOFT DECORATIVE LAMINATE
- HARD DECORATIVE LAMINATE
- SANDWICH PANEL
SINGLE FILM EVALUATION

- LOI
- $D_S$ AT 1.5 AND 4 MINUTES
- $D_M$
- CO, HF, AND HCL AT 4 MINUTES
- 18 CANDIDATES
EVALUATION FORMULAS

\[ A = \left( \frac{\text{LOI}}{300} \right) + \left( \frac{50 - D_S(1.5)}{450} + \frac{100 - D_S(4.0)}{900} + \frac{200 - D_M}{1800} \right) \]

\[ + \left( \frac{100 - \text{CO}}{900} + \frac{10 - \text{HCL}}{90} + \frac{100 - \text{HF}}{900} \right) \]

\[ B = \left( \frac{\text{LOI}}{100} \right)^{1/3} \times \left[ \left( \frac{50 - D_S(1.5)}{50} \right) \left( \frac{100 - D_S(4.0)}{100} \right) \left( \frac{200 - D_M}{200} \right) \right]^{1/9} \]

\[ \times \left[ \left( \frac{100 - \text{CO}}{100} \right) \left( \frac{10 - \text{HCL}}{10} \right) \left( \frac{100 - \text{HF}}{100} \right) \right]^{1/9} \]
FURTHER EVALUATION

- PRINTABILITY
- EMBOSABILITY
- UV STABILITY
- HEAT RELEASE
- SMOKE EMISSION
- TOXIC GAS EMISSION
- FLAME SPREAD INDEX
- 5 CANDIDATES
SMOKE EMISSION

- NYLON
- POLYESTER
- PVF$_2$
- PVF (CLEAR)
- FM-PVF
- PVF (WHITE)
- ARAMID
FLAME SPREAD INDEX

$I_S$

0  5  10  15  20  25

FM-PVF  PVF  PVF  ARAMID  NYLON  PVF$_2$
(CLEAR)  (WHITE)  POLYESTER

33.2  31.5
EVALUATION FORMULAS

\[ A = \left( \frac{35 - I_S}{105} \right) + \left( \frac{50 - D_S(1.5)}{450} + \frac{100 - D_S(4.0)}{900} + \frac{100 - D_M}{900} \right) + \left( \frac{200 - CO}{2400} + \frac{10 - HCN}{120} + \frac{10 - NO_X}{120} + \frac{150 - HF}{1800} \right) \]

\[ B = \left( \frac{35 - I_S}{35} \right)^{1/3} x \left[ \left( \frac{50 - D_S(1.5)}{50} \right) \left( \frac{100 - D_S(4.0)}{100} \right) \left( \frac{100 - D_M}{100} \right) \right]^{1/9} \]

\[ x \left[ \left( \frac{200 - CO}{200} \right) \left( \frac{10 - HCN}{10} \right) \left( \frac{10 - NO_X}{10} \right) \left( \frac{150 - HF}{150} \right) \right]^{1/12} \]
CURRENT CANDIDATES

- TOP FILM
  - PVF (CLEAR)

- SUBSTRATE FILMS
  - ARAMID
  - FM-PVF
  - PVF (WHITE)
  - PVF$_2$
  - DUPONT EXPERIMENTAL
  - FPE-P
FUTURE WORK

• SOFT DECORATIVE LAMINATES
  • SMOKE AND TOXIC GAS EMISSION
  • 60 SEC VERTICAL FLAMMABILITY
  • PEEL STRENGTH

• HARD DECORATIVE LAMINATES
  • PEEL STRENGTH
  • AESTHETICS
  • ABRASION RESISTANCE
PHASE IV – DECORATIVE INK DEVELOPMENT
MATERIAL REQUIREMENTS

- 5 MIL FILM
- LOI ≥ 35
- $D_s \leq 20$ (2.5 W/CM$^2$, 4 MINUTES)
- TGA (N$_2$ AND AIR) RT → 250° C
- $LC_{50} \geq 70$ MG/L
APPROACH

- UV CURED INKS
- VISCOSITY VARIATION
- AIR QUALITY REGULATIONS
- TECHNOLOGY AVAILABLE

- SUBCONTRACT
  - K.C. COATINGS, INC.
  - 6-MONTH EFFORT
  - NEGOTIATIONS IN PROGRESS
SMOKE EMISSION

KC-4900 (ACRYLIC)

UV-1 (URETHANE)

UV-2 (EPOXY)

MINUTES
TOXIC GAS EMISSION

1 - KC-4900 (ACRYLIC)
2 - UV-1 (URETHANE)
3 - UV-2 (EPOXY)

PPM (4 MIN)
FABRICATION PROGRAMS
OVERVIEW

- BEGAN IN DECEMBER, 1977
- INTERIOR SANDWICH PANELS
- LAVATORY PANEL FABRICATION (NAS9 – 13000)
- INTERIOR PANEL FABRICATION (NAS2 – 10004)
LAVATORY PANEL FABRICATION

- NASA-JSC
- 9 PANELS
- DC-10 LAVATORY SIMULATION
LAVATORY SCHEMATIC
DOUBLE DECORATED PANEL

- PVF (CLEAR)
- INK
- PVF (WHITE)
- CIBA GEIGY 917G
- NOMEX CORE + FOAM
SINGLE DECORATED PANEL

- PVF (CLEAR)
- INK
- PVF (WHITE)
- CIBA GEIGY 917G
- NOMEX CORE
- CIBA GEIGY 917G
INTERIOR PANEL. FABRICATION

- NASA-ARC
- 56 PANELS
- 40 X 96 X 1 INCH
- FAA-NAFEC
- VARIOUS THERMOPLASTIC FILMS
PANEL MAKEUP

- TOP FILM
- INK
- SUBSTRATE FILM
- ADHESIVE
- PREPREG
- NOMEX/PHENOLIC CORE
- PREPREG
# PANEL MATERIALS

<table>
<thead>
<tr>
<th>DECORATIVE FILM</th>
<th>ADHESIVE</th>
<th>PREPREG</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOP</td>
<td>INK</td>
<td>SUBSTRATE</td>
</tr>
<tr>
<td>1 MIL PVF</td>
<td>ACRYLIC</td>
<td>2 MIL PVF</td>
</tr>
<tr>
<td>1 MIL PVF +3 MIL PVC</td>
<td>ACRYLIC</td>
<td>2 MIL PVF</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>3 MIL PC</td>
</tr>
<tr>
<td>1 MIL PVF</td>
<td>-</td>
<td>2 MIL PVF</td>
</tr>
<tr>
<td>1 MIL PVF</td>
<td>-</td>
<td>5 MIL PC</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>3 MIL PVF</td>
</tr>
<tr>
<td>1 MIL PVF</td>
<td>ACRYLIC</td>
<td>2 MIL PVF</td>
</tr>
</tbody>
</table>
ADVANCED RESIN MATRICES FOR COMPOSITES

A Presentation Made At
THE FIREMEN MEETING
Seattle, Washington
March 2, 1979

D. A. KOURTIDES
NASA - ARC
SELECTION CRITERIA FOR RESIN MATRICES

- HIGH CHAR YIELD
- HIGH OI, LOW SMOKE & TOXICITY
- GOOD ELEVATED TEMPERATURE MECHANICAL PROPERTIES
- GOOD THERMAL OXIDATIVE STABILITY
- HIGH HUMIDITY RESISTANCE
- CHEMICAL AND RADIATION RESISTANCE
- GOOD FATIGUE AND TOUGHNESS PROPERTIES
- COMPATIBLE PROCESSING, QUALITY CONTROL, AVAILABILITY AND COST TO STATE-OF-THE-ART EPOXY RESINS
### RESIN MATRICES FOR COMPOSITES

<table>
<thead>
<tr>
<th>RESIN/CURING AGENT</th>
<th>TYPICAL CHEMICAL STRUCTURE</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPOXY RESIN BASED ON METHYLENE DIANILINE CURED WITH AROMATIC AMINE OR 4,4' DIAMINO DIPHENYL SULPHONE (DDS) (SAMPLE 1)</td>
<td><img src="image1" alt="Chemical structure 1" /></td>
</tr>
<tr>
<td>EPOXY RESIN BASED ON DIGLYCIDYL ETHER OF BISPHENOL A (DGEBA) OR 9,9'-BIS-(4-HYDROXYPHENYL) FLUORENE (DGEBF) OR BLENDS CURED WITH TRIMETHOXYBOROXINE (TMB) OR MDA OR DDS (SAMPLE 2)</td>
<td><img src="image2" alt="Chemical structure 2" /></td>
</tr>
<tr>
<td>PHENOLIC NOVOLAC RESIN BASED ON CONDENSATION OF DIMETHOXY-P-XYLENE AND PHENOL CURED WITH HEXAMINE (SAMPLE 3)</td>
<td><img src="image3" alt="Chemical structure 3" /></td>
</tr>
</tbody>
</table>
RESIN MATRICES FOR COMPOSITES

RESIN CURING AGENT

POLYBISMALEIMIDE PREPOLYMER
(SAMPLE 4)

BIS(4-GLYCIDYL-2-METHOXYPHENYL)PHENYLPHOSPHONATE
EPoxy RESIN CURED WITH
N,N-DIETHYLAMINOPROPYLAMINE (DEPA)
(SAMPLE 5)

TYPICAL CHEMICAL STRUCTURE
# PROCESSING CONDITIONS FOR RESINS AND LAMINATES

<table>
<thead>
<tr>
<th>RESIN</th>
<th>PURE RESIN</th>
<th></th>
<th>POST CURE</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPOXY RESIN (SAMPLE 1)</td>
<td>NMA OR DEAPA OR DDS</td>
<td>DDS, 30 pph, 150°C – 1 hr</td>
<td>190°C – 4 hrs</td>
</tr>
<tr>
<td>EPOXY RESIN, DGEBA/DGEBF (SAMPLE 2)</td>
<td>TMB OR DDS</td>
<td>TMB, 30 pph, 135°C – 3 hrs</td>
<td>180°C – 3 hrs, 218°C – 3 hrs, N2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>RESIN/SOLVENT</th>
<th>PREPREG</th>
<th>CURE</th>
<th>POST CURE</th>
</tr>
</thead>
<tbody>
<tr>
<td>(SAMPLE 1)/MEK</td>
<td>AIR DRY, 80°C – 10 min</td>
<td>163°C – 10 min, 340 KN/m² – 2 hrs</td>
<td>190°C – 4 hrs</td>
</tr>
<tr>
<td>(SAMPLE 2)/MEK</td>
<td>AIR DRY, 100°C – 15 min</td>
<td>200°C – 10 min, 340 KN/m² – 2 hrs</td>
<td>218°C – 3 hrs, N2</td>
</tr>
</tbody>
</table>
# Processing Conditions for Resins and Laminates

## Resin | Pure Resin | Catalyst | Cure | Post Cure
---|---|---|---|---
Phenolic Novolac (Sample 3) | | 160°C - 1.5 hrs | 200°C - 1 hr
Polybismaleimide (Sample 4) | | 200°C - 3 hrs | |
Phosphorylated Epoxy (Sample 5) | DEAPA | DEAPA/BAPMP | 180°C - 4 hrs

## Resin/Solvent | Laminate
---|---
**Prepreg** | **Cure** | **Post Cure**
(Sample 3)/MEK | 65°C - 15 min | 177°C - 1 hr | 188°C - 2 hrs
 | 115°C - 20 min | 680 KN/m² | |
(Sample 4)/MEK | AIR DRY, 79°C - 15 min | 200°C - 3 hrs | |
 | 120°C - 20 min | 680 KN/m² | |
(Sample 5)/MEK | AIR DRY, 80°C - 10 min | 180°C - 10 min | |
 | 120°C - 20 min | | 200°C - 4 hrs
EFFECT OF DGEBF MOLE FRACTION IN THE BLEND OF DGEBA/DGEBF ON THE CHAR YIELD OF THE COPOLYMER AT 700°C

CONDITIONS:
HEATING RATE 10°C/min, N₂

CHAR YIELD, wt. %
0 10 20 30 40 50 60 70 80 90 100
DGEBF, mole %

ORIGINAL PAGE IS OF HCER QUALITY
DRYING CURVES FOR BISMALEIMIDE/181-PREPREGS

○ NMP, 105°C, DRY RESIN CONTENT 34%
□ NMP, 140°C, DRY RESIN CONTENT 35%
△ NMP, 160°C, DRY RESIN CONTENT 39%
+ NMP, 180°C, DRY RESIN CONTENT 39%

SOLVENT CONTENT, %

TIME, min

230
DYNAMIC THERMOGRAVIMETRIC ANALYSES OF RESINS

1. EPOXY RESIN-DDS
2. EPOXY RESIN, DGEBA/DGEBF
3. PHENOLIC NOVOLAC
4. BISMALEIMIDE
5. PHOSPHORYLATED EPOXY

CHAR YIELD, wt.

CONDITIONS: 10°C/min, N₂

TEMPERATURE, °C

0 100 200 300 400 500 600 700 800

1 31%
2 39%
3 50%
4 55%
5 33%
DYNAMIC THERMOGRAVIMETRIC ANALYSIS OF BISMALLEIMIDE RESIN (SAMPLE 5)

CONDITIONS: 10°C min, N₂

CHAR YIELD, wt %

- MOLDED CURED RESIN
- UNCURED RESIN

TEMPERATURE, °C

20 40 60 80 100
100 200 300 400 500 600 700 800 900
SMOKE EVOLUTION OF RESIN/181 GLASS LAMINATES

1. EPOXY RESIN-DDS
2. PHENOLIC NOVOLAC
3. BISMALEIMIDE, 35% RESIN
4. BISMALEIMIDE, 40% RESIN

NBS SMOKE CHAMBER
FLAMING
2.5 watts/cm²

TIME, min

SPECIFIC OPTICAL DENSITY, Dₜ

0 1 2 3 4 5 6 7 8 9 10
EFFECT OF CHAR YIELD OF THERMOSET POLYMERS ON OXYGEN INDEX

SAMPLE RESIN
1 EPOXY-DDS (STATE-OF-THE-ART)
2 EPOXY (DGEBA/DGEBF)—TMB
3 PHENOLIC NOVOLAC
4 BISMALEIMIDE
5 PHOSPHORYLATED EPOXY

CALCULATED FROM REFERENCE 7

OXYGEN INDEX AT 23°C

PERCENT WEIGHT REMAINING AT 800°C, N₂
EFFECT OF TEMPERATURE ON FLEXURAL STRENGTH OF COMPOSITES

1. EPOXY, 181 E GLASS FABRIC, 40% RESIN
2. PHENOLIC, 181 E GLASS FABRIC, 40% RESIN
3. BISMALEIMIDE, 181 E GLASS FABRIC, 40% RESIN
HCN CONCENTRATION HISTORY

BISMALEIMIDE

EPOXY - DDS

F - FLAMING

NF - NON FLAMING

PPM x 10^2

EXPOSURE TIME, MIN

F, 700°C

NF, 600°C

NF, 490°C

F, 680°C
CONCLUSIONS

DGEBA/DGEBF epoxy cured with TMG exhibited highest OI and $\gamma_c$ than all other epoxy resins with processing parameters comparable to conventional epoxies.

Phenolic-novolac resin exhibited lowest $D_s$ than all other resin systems.

Bismaleimide resin exhibited highest OI and $\gamma_c$ than all other resin systems. Processing parameters comparable to phenolics.

Above resins excellent candidates for resin matrices for glass or graphite composites.
A COMPARATIVE STUDY OF THE TOXICITY OF THE COMBUSTION PRODUCTS OF TEDLAR AND A PHOTOREACTIVE-POLYESTER FILM

David G. Farrar

Flammability Research Center
University of Utah
391 South Chipeta Way
P. O. Box 8089
Salt Lake City, Utah 84108
INTRODUCTION

The relative toxicity in the rat resulting from a 30-minute exposure to the combustion products of two materials, Tedlar and a fluorenone-polyester film, has been assessed. The combustion products were generated into a static exposure system using a laboratory-scale furnace. The toxicity was assessed using the primary measurements employed in a more detailed overall toxicity evaluation. The endpoints employed in the assessment were incapacitation and death. The toxicological events observed during the 30-minute exposure are reported here. This report does not consider any post-exposure consequences of the exposure.

METHODS

Combustion of Materials

The sample sizes used in this study were chosen to produce nominal combustion product concentrations ranging from 5 to 40 grams per cubic meter. These concentrations were the quotient of the number of grams of sample introduced into the furnace divided by the chamber capacity (.064 m$^3$).

Exposure System

The exposure chamber used for these studies was of an octagonal configuration with a nominal volume of 60 L. A circular port was present on each of four faces of the chamber, approximately 6" above the floor. Into these ports were inserted four male pigmented Long-Evans rats (350-450 gm) held in tubular restrainers, so that they could be exposed to the combustion atmosphere in a head-only fashion. The furnace and combustion conditions used in the study were those reported by Potts and
Lederer (1977). The materials were combusted in both the flaming and nonflaming modes. The furnace was mounted below the chamber such that the mouth of the furnace was essentially flush with the bottom of the chamber. The furnace held a Monel beaker in which the sample was combusted. A PTFE-coated cone was placed above the furnace to shield the animals from direct flame radiation, and to aid in convection of the combustion products.

Toxicological Evaluation

Rats were exposed to the combustion atmospheres for a period of 30 minutes. To determine incapacitation, all animals were monitored for performance of the leg-flexion avoidance response, using a method similar to that described by Packham et al. (1978).

Analysis of the combustion product atmosphere was carried out throughout each exposure. Combustion atmospheres were sampled at 3.5-minute intervals for CO, CO₂, and O₂, which were detected using gas chromatographic techniques. Temperatures inside the chamber were monitored utilizing a chromel-alumel thermocouple at the level of the animals, with an external reference cold junction and recorded on a strip chart recorder.

The ability of each material to generate CO under the conditions of the experiment was expressed as the CO-generating capacity (mg CO/gm material). This was calculated for each exposure using the following equation:

$$\text{CO-generating capacity} = \frac{\text{ppm} \times \text{chamber vol. (ft)} \times \text{M.W.} \times 10^{-3}}{\text{sample wt.} \times 25.79^*}$$

* mole volume in Salt Lake City

241
The relationship between the percentage of population affected versus concentration of combustion products (gm/m$^3$ of material introduced into the furnace) was established employing the statistical methodology described by Miller and Tainter (1944). This relationship was obtained for both incapacitation and death. The EC$_{50}$ (concentration causing incapacitation in 50% of the population) and LC$_{50}$ (concentration causing death in 50% of the population) were calculated for each material, under the two combustion conditions.

Animals surviving the exposure were subjected to a behavioral examination immediately post-exposure. This examination considered standard observations designed to determine their behavioral, motor coordination, central nervous system and autonomic capabilities. Blood samples were obtained by cardiac puncture from those animals that died during the exposure, and carboxyhemoglobin (COHb) levels were determined using an Instrumentation Laboratories 282 Co-Oximeter.

Animals surviving the exposure were retained for 14 days. During this post-exposure period they were weighed on a regular basis and any deaths occurring were recorded. Observations that were made during this period will be presented in an addendum to this report. This will include a re-calculation of the respective LC$_{50}$ values based upon the total number of deaths observed both during the 30-minute exposure and the 14-day post-exposure period.

Materials

Both materials, Tedlar and the fluorenone-polyester film, were supplied by NASA-Ames Laboratory. Both materials were supplied as thin films. The Tedlar sample was opaque, and the fluorenone-polyester film was clear.
<table>
<thead>
<tr>
<th>Combustion Condition</th>
<th>Material</th>
<th>Furnace Temperature (°C)</th>
<th>CO Generation mg/gm</th>
<th>Incapacitation EC50 ± S.E.</th>
<th>Death (30 min.) LC50 ± S.E.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nonflaming</td>
<td>Tedlar</td>
<td>700</td>
<td>101</td>
<td>18.8 ± 6.8</td>
<td>34.0*</td>
</tr>
<tr>
<td></td>
<td>Fluorenone-polyester</td>
<td>720</td>
<td>240</td>
<td>10.9*</td>
<td>17.2</td>
</tr>
<tr>
<td>Flaming</td>
<td>Tedlar</td>
<td>800</td>
<td>47</td>
<td>21.0 ± 6.8</td>
<td>&gt; 40</td>
</tr>
<tr>
<td></td>
<td>Fluorenone-polyester</td>
<td>780</td>
<td>227</td>
<td>10.7 ± 0.8</td>
<td>13.2 ± 1.4</td>
</tr>
</tbody>
</table>

*insufficient data to calculate standard error (S.E.)
Carbon Monoxide Levels

FLUORENONE-POLYESTER

TEDLAR

○ 22.5 gm/m³ NF
● 20.0 gm/m³ F

○ 20.7 gm/m³ NF
● 17.2 gm/m³ F

Time (Mins.)
TABLE 5a

COMPARISON OF TOXICOLOGICAL OBSERVATIONS ON SURVIVING RATS EXPOSED TO THE NON-FIYING COMBUSTION PRODUCTS OF A POLYESTER FILM AND POLYVINYL FLUORIDE FILM (PVF)

<table>
<thead>
<tr>
<th>Observations</th>
<th>Concentration gm/m$^3$</th>
<th>Polyester film</th>
<th>PVF film</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>10.3</td>
<td>11.6</td>
</tr>
<tr>
<td>Incapacitation</td>
<td></td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>(mean time - secs.)</td>
<td></td>
<td>(-)</td>
<td>(1139)</td>
</tr>
<tr>
<td>Behavior</td>
<td>n=</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>+ activity</td>
<td></td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>+ sensitivity to touch</td>
<td></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>+ pain (tail pinch)</td>
<td></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>+ muzzle response</td>
<td></td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Motor Coordination</td>
<td></td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>+ righting reflex</td>
<td></td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>+ hang response</td>
<td></td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>+ posture</td>
<td></td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Concentration gm/m³</td>
<td>Polyester film</td>
<td>PVF film</td>
<td></td>
</tr>
<tr>
<td>---------------------</td>
<td>----------------</td>
<td>----------</td>
<td></td>
</tr>
<tr>
<td>10.3</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>11.6</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>16.2</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>5.0</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>7.9</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>22.5</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>29.3</td>
<td>3</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

**CNS**
- **+ startle response**
  - Polyester film: 0
  - PVF film: 0
- **tremors, twitches, convulsions**
  - Polyester film: 0
  - PVF film: 0

**Autonomic**
- **eyes - + corneal reflex**
  - Polyester film: 0
  - PVF film: 0
- **+ lachrymation**
  - Polyester film: 3
  - PVF film: 2
  - 7.9: 4
  - 22.5: 4
  - 29.3: 0
- **+ clarity**
  - Polyester film: 0
  - PVF film: 0
  - 7.9: 4
  - 22.5: 4
  - 29.3: 0
- **salivation**
  - Polyester film: 0
  - PVF film: 1
  - 7.9: 1
  - 22.5: 4
  - 29.3: 2
- **nasal discharge**
  - Polyester film: 1
  - PVF film: 1
  - 7.9: 0
  - 22.5: 4
  - 29.3: 3
- **visible respiration - abnormal**
  - Polyester film: 4
  - PVF film: 1
  - 7.9: 4
  - 22.5: 2
  - 29.3: 4
Changes In Body Weight

Body Weight gm

- 460
- 420
- 380
- 340

DAYS

-6 -4 -2  0  2  4  6  8  10  12  14

exposure

- Tedlar 29 gm/m³ NF
- Tedlar 40 gm/m³ F
- ISO FPE 16gm/m³ NF
- ISO FPE 13gm/m³ F
<table>
<thead>
<tr>
<th>Material</th>
<th>Combustion Condition</th>
<th>Furnace Temperature</th>
<th>CO generated mg/gm</th>
<th>HCN generated mg/gm</th>
<th>EC50 ± S.E.</th>
<th>LC50 ± S.E.</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPOXY</td>
<td>NF</td>
<td>600°C</td>
<td>74.6 ± 10.7 n=8</td>
<td>3.2 ± 0.7 n=10</td>
<td>4.14 ± 0.87</td>
<td>11.01 ± 2.09</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>680°C</td>
<td>50.5 ± 13.1 n=8</td>
<td>2.5 ± 0.6 n=8</td>
<td>6.23 ± 1.04</td>
<td>7.26</td>
</tr>
<tr>
<td>BISMALEIMIDE</td>
<td>NF</td>
<td>490°C</td>
<td>27.5 ± 5.2 n=9</td>
<td>1.4 ± 0.3 n=9</td>
<td>20.13 ± 3.88</td>
<td>41.85 ± 3.15</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>700°C</td>
<td>85.6 ± 8.7 n=10</td>
<td>2.9 ± 0.9 n=10</td>
<td>6.83 ± 1.45</td>
<td>14.98 ± 2.22</td>
</tr>
</tbody>
</table>
Carbon Monoxide Generation From Non-Flaming Combustion of Resins

EPOXY
- 22 gm/m³
- 11 gm/m³
- 6 gm/m³

BISMALEIMIDE
- 43 gm/m³
- 28 gm/m³
- 13 gm/m³

Time (Min)
Hydodgen Cyanide Generation From Non-Flaming Combustion of Resins

**EPOXY**
- ○ 22 gm/m³
- ● 11 gm/m³
- □ 6 gm/m³

**BISMALEIMIDE**
- ● 43 gm/m³
- □ 28 gm/m³
- ○ 13 gm/m³

Time (Mins.)

HCl (ppm) x 10^2
FIRE AND SMOKE RETARDANT MATERIALS DEVELOPMENT

W.A. Mueller
FLAME AND SMOKE RETARDANCE IN PLASTICS MAY BE OBTAINED BY USING INHERENTLY NONFLAMMABLE RESINS, BY THE USE OF ADDITIVES, AND BY USING FILLERS. ACTIVE FILLERS ABSORB HEAT AND RELEASE COOLING GASES SUCH AS WATER VAPOR. THE USE OF FILLERS ALTERS PHYSICAL PROPERTIES, AND, IN PARTICULAR, CAUSES A DECREASE IN IMPACT RESISTANCE, AN ESSENTIAL PROPERTY OF WOODED PARTS FOR AIRCRAFT INTERIORS. THE PRESENT RESEARCH SEeks TO PROVIDE A MECHANISM FOR DISSIPATION OF IMPACT ENERGY IN FILLED POLYMERS BY USING FILLERS WITH A LOW MODULUS COATING WHICH WILL DISSIPATE ENERGY THROUGH SHEARING AND CRAZING INSTEAD OF FRACTURE. THE APPROACH OFFERS THE ADVANTAGES OF LOW COST, LOW TOXICITY, AND APPLICABILITY TO VARIOUS RESINS.
SEVERAL METHODS MAY BE USED TO APPLY COATING TO FILLER. FOR MINERAL FILLERS WITH ALKALINE SURFACES, INCORPORATION OF SMALL AMOUNTS OF ACIDIC SITES IN THE COATING AFFORDS READY BONDING BETWEEN THE TWO MATERIALS. A COPOLYMER OF 2-ETHYLHEXYL ACRYLATE (EHA) AND ACRYLIC ACID (AA) HAS BEEN SYNTHESIZED AND EVALUATED. IT IS CROSSLINKED BY THE FILLER PARTICLES, PROVIDING A RUBBERY MATERIAL AND SOME CONTROL OVER MODULUS.
FILLER PARTICLE SCHEMATIC

LOW MODULUS COATING

BULK RESIN

ACTIVE FILLER

REQUIREMENTS -
- COATING MUST HAVE LOW $T_g$, $<-40^\circ C$
- BONDED TO FILLER AND RESIN
- CONVENIENT PROCESSING
THE RESINS SELECTED FOR INVESTIGATION WERE POLYPROPYLENE (PP) AND
ETHYLENE-ACRYLIC ACID COPOLYMER (EAA). MAGNESIUM HYDROXIDE AND
ALUMINA TRIHYDRATE ARE EXAMPLES OF ACTIVE MINERAL FILLERS THAT ARE
STABLE AT THE REQUIRED PROCESSING TEMPERATURES. POLYVINYL ALCOHOL
FIBERS OFFER RELEASE OF WATER ON DECOMPOSITION, LIGHT WEIGHT, AND
ARE KNOWN TO IMPART EXCELLENT IMPACT RESISTANCE TO THERMOPLASTIC
POLYESTER MOLDING COMPOUNDS. 2-ETHYLHEXYL ACRYLATE-ACRYLIC ACID
COPOLYMER BONDS READILY TO MAGNESIUM HYDROXIDE AND ALUMINA TRIHYDRATE,
AND IS COMPATIBLE WITH THE RESINS.
EXPERIMENTAL PLAN

RESINS

POLYPROPYLENE (PP)
ETHYLENE-ACRYLIC ACID COPOLYMER (EAA)

FILLERS

- MAGNESIUM HYDROXIDE
- ALUMINA TRIHYDRATE
- POLYVINYL ALCOHOL FIBERS

FILLER PROCESSING

- 2-ETHYL HEXYL ACRYLATE/ACRYLIC ACID COPOLYMER

2, 8, 16 WT. % OF FILLER

MIX

MOLD FOR TESTS
BEST RESULTS UNDER NON-FLAMING CONDITIONS ARE WITH EMA-ALUMINA TRIHYDRATE. PVA FIBERS CAUSE MUCH SMOKE, MORE THAN 'SMOKY' ABS. THESE SAMPLES ALL SHOW SATISFACTORY IMPACT RESISTANCE.
SMOKE GENERATION — NON FLAMING
(NBS SMOKE CHAMBER)

![Graph showing specific optical density over time for different materials]

- 72: EAA, PVA FIBERS
- 104: ABS
- 96: EAA, AL₂O₃ • 3H₂O +
- 98: PVA FIBERS
- 42: EAA, AL₂O₃ • 3H₂O
RESULTS UNDER FLAMING CONDITIONS ARE MARKEDLY DIFFERENT FROM NON-FLAMING CONDITIONS. THE EAA/PVA COMBINATION, THE BEST UNDER FLAMING CONDITIONS, IS THE WORST UNDER NON-FLAMING CONDITIONS. THE EAA-ALUMINA TRIHYDRATE COMBINATION, WHICH WAS THE BEST IN NON-FLAMING CONDITIONS, IS ALSO VERY GOOD IN FLAMING CONDITIONS. NOTE THAT MIXTURES OF ALUMINA TRIHYDRATE AND PVA FIBERS ARE SUBSTANTIALLY WORSE THAN EITHER ALONE. THIS MAY BE CAUSED BY A CHANGE IN THE MECHANISM OF DECOMPOSITION.
SMOKE GENERATION — FLAMING
(NBS SMOKE CHAMBER)

\[ D_s \text{ SPECIFIC OPTICAL DENSITY} \]

\[ 0 \leq \text{TIME (MIN)} \leq 20 \]

- 96 AND 98 = EAA, \( \text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O} \) + PVA FIBERS
- 42 = EAA, \( \text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O} \)
- 72 = EAA, PVA FIBERS
THE RESIN-MINERAL FILLER COMBINATION WITH THE BEST IMPACT PROPERTIES was EAA-alumina trihydrate. A filler coating level of 8% gave the best results. Magnesium hydroxide-filled materials tended to be brittle. The impact resistance of polypropylene filled with coated fillers was less than unfilled polypropylene. Polyvinyl alcohol fibers markedly improved the impact resistance of both PP and EAA.
RELATIVE IMPACT RESISTANCE OF VARIOUS MATERIALS

- ABS
- EAA - PVA FIBERS
- EAA - AL₂O₃ 3H₂O + PVA FIBERS
- EAA - AL₂O₃ 3H₂O
- PP - HIGH IMPACT
- EAA - UNFILLED
- PP - UNFILLED*
- PP - AL₂O₃ 3H₂O

* = BROKE IN TEST
THE USE OF HIGH LEVELS OF ACTIVE FILLERS CAN PRODUCE A MOLDING COMPOUND WITH A SATISFACTORY BALANCE OF PROPERTIES, HOWEVER A WEIGHT PENALTY IS INCURRED. THIS PENALTY IS ESTIMATED AT 200 - 250 LBS FOR AN L1011 OR 747 AIRCRAFT. PVA FIBER GIVES EXCELLENT RESULTS EXCEPT UNDER NON-FLAMING CONDITIONS. THIS MAY BE DUE TO A CHANGE IN THE MECHANISM OF DECOMPOSITION. IF SO, CATALYSIS OF THE REACTION UNDER NON-FLAMING CONDITIONS MAY REDUCE SMOKE EVOLUTION, AND ADVANTAGE COULD THEN BE TAKEN OF THE LIGHT WEIGHT OF THE PVA-EAA COMBINATION.
SUMMARY

EAA-ALUMINA TRIHYDRATE
- LOW SMOKE
- LOW TOXICITY
- LOW COST
- SATISFACTORY IMPACT RESISTANCE
- WEIGHT PENALTY (200 - 250 LBS)

EAA-PVA
- LOW TOXICITY
- HIGH IMPACT RESISTANCE
- WEIGHT BENEFIT (125 - 150 LBS)
- LOW SMOKE UNDER FLAMING CONDITIONS
- HIGH SMOKE UNDER NON-FLAMING CONDITIONS
THERMOCHEMICAL MODELING
505-08-25
Kumar Ramohalli
March 1, 1979

• AIMS

  • PREDICT FIRE AND SMOKE BEHAVIOR USING ONLY
  • INGREDIENT THERMOCHEMICAL PROPERTIES
  • GEOMETRY AND FLOW

  } NON-EMPERICAL

• SUGGEST ECONOMICAL METHODS FOR BETTER MATERIALS

• TRANSFER TO INDUSTRY

• PROGRESSIVE STEPS IN COMPLEXITY
HONEYCOMB SANDWICHES

- CONDUCTION:
  SOLID NOMEX: \[ k_{\text{nomex}} \times A_{\text{nomex}} = 0.092 \times 0.0024 \times 2.2 \times 10^{-4} \]  
  AIR COLUMNS: \[ k_{\text{air}} \times A_{\text{air}} = 0.020 \times 0.01 \times 2.0 \times 10^{-4} \]  
  RATIO \approx 1

- SIMPLIFICATIONS NOT FEASIBLE

- CONVECTION
  \[ R = G \cdot Pr = \frac{g \beta \theta w x^5}{\nu^2} \cdot \frac{\mu \epsilon_p}{k} \]
  \(< 1700 \text{ NO CONVECTION} \]
  \([1700-47000 \text{ CELLULAR}] \]
  \(> 47000 \text{ TURBULENCE} \)
• AVAILABLE SOLUTIONS AND EXPERIMENTS

\[ \dot{q}' = \frac{k_e}{b} (T_1 - T_2) \]

**SIGNIFICANT INCREASE IN HEAT TRANSFER**

• SOLUTION FOR SPECIFIC CASE NOT AVAILABLE
  - CHEMICAL DEGRADATION
  - DEBONDING
  - GAS EVOLUTION AND FLOW

**APPROACH**

[Graph showing typical aircraft application with log \( G \) vs. \( \log(\text{Pr}) \).]
SUMMARY
(Feբ 1979)

- COMPLEX CHARRING CASE SOLVED
- CONFIRMED BY EXPERIMENTS
- PROBLEMS IDENTIFIED IN SANDWICH PANELS
- FORMULATION COMPLETED

SPINOFFS
- APPLICATIONS IN GRAPHITE FIBER COMPOSITES
- THERMAL PERFORMANCE CONTROL (COATED FILLERS AND PROPELLANTS)

AIAA PAPER 79-0018
The fluorenon polyester ISO FPE of ISOVOLTA Comp., Austria

In the last two years the Isovolta Comp. has payed attention to a family of polymers which are thermally stable, of low flammability and which show in the case of combustion a low toxic gas emission. The aim was to cast a transparent film of a solution, in which no flame retardants are used to achieve the flammability requirements.

ISO FPE consists only of carbon, hydrogen and oxygen, that is to say that no nitrogen, fluorides, sulfur or antimony are incorporated in the polymer.

The selection of monomers was based on the aspects shown in previous papers, namely that the char yield and the amount of incombustible gases formed in thermal decomposition are the most significant characteristics of flame resistance, even in a quantitative way. For a large number of well known polymers the char yield under nitrogen atmosphere due to pyrolysis was determined. The char yield is related to the chemical structure of the polymer in a distinct way. Also, the amount of char yield can be predicted from the structure. Secondly, there is a significant relation between the char yield and the limiting oxygen index. The LOI is measured according to ASTM D 2863-76.

The linear correlation between the char yield under nitrogen atmosphere and the LOI is represented by the equation:

\[
\text{LOI} = 17.5 + 0.4 \cdot Y_{800}^C
\]

The char yield under nitrogen atmosphere is related to the chemical structure of the polymer by the equation:

\[
Y_{800}^C = \frac{1}{M} \cdot 1200 \cdot \sum (CFT)_i
\]
M means the molecular weight per structural unit.

(CFT) the group contribution to the char forming tendency.

The experimental results match the theoretical values very well. Doing a thermogravimetric analysis a char yield of 58% weight retention is found (Fig 1). This causes a theoretical LOI of 40.7%, the value found by experiment is 40.

The group contribution to the char forming tendency is shown in the following table.

<table>
<thead>
<tr>
<th>Group</th>
<th>Contribution to CFT (modified)</th>
</tr>
</thead>
<tbody>
<tr>
<td>methyl</td>
<td>CH$_3^-$</td>
</tr>
<tr>
<td>methylene</td>
<td>CH$_2^=$</td>
</tr>
<tr>
<td>isopropyldiene</td>
<td>C(CH$_3$)$_2^=$</td>
</tr>
<tr>
<td>phenyl</td>
<td>C$_6$H$_5^-$</td>
</tr>
<tr>
<td>phenylene</td>
<td>C$_6$H$_4=0$ m p</td>
</tr>
<tr>
<td>fluorene-9-ylidene</td>
<td>+ 10</td>
</tr>
</tbody>
</table>

This table allows to predict the flammability behaviour of groups used to compose monomers.

In a comprehensive study of P.W. Morgan a large number of bisphenols was studied. However, only two of these bisphenols showed sufficient quality of polymer resulting in high value of LOI. This fact is due to the missing of groups with negative contribution to the char forming tendency. The monomer engaged for the preparation of ISO iPE is the 9,9-Bis(4-hydroxyphenyl)fluorenone, or fluorenone, which we call Diphenol F.
Diphenol F is prepared by a modification of the synthesis of Morgan in batches of 100 lb from fluorenone, phenol, hydrogen chloride and a co-catalyst. The synthesis is conducted by Isovolta Company in Austria. The yield of Diphenol F after one crystallisation process from 1,2 dichloroethane, is more than 90 percent.

Technical datas are shown in the table below:

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melting point</td>
<td>225°C</td>
</tr>
<tr>
<td>Elemental analysis</td>
<td></td>
</tr>
<tr>
<td></td>
<td>% C</td>
</tr>
<tr>
<td>calculated</td>
<td>85.69</td>
</tr>
<tr>
<td>experimental</td>
<td>85.54</td>
</tr>
</tbody>
</table>

The purity of Diphenol F is checked by high pressure liquid chromatography and yields a value of 99 percent.

Synthesis of ISO-FPE

One of the most common syntheses of polyesters is the reaction of chlorides of dicarboxylic acids with bisphenols. However, there are several ways described in the literature to conduct the synthesis of these polyesters:

The LOI of polyesters produced by solution condensation at high temperatures yields a low value compared to polyesters prepared with solution condensation at room temperature. The reason is, that even a low concentration of products which is obtained by decomposition due to these drastic temperature conditions causes the low value of LOI. On the other hand, the interfacial condensation is carried out at room temperature. Since Diphenol F shows a low solubility in aqueous sodium hydroxyde a solution condensation with stoichiometric amounts of hydrogen chloride acceptors - such as triethylamine or others - is preferred when working at room temperature. The advantage of this process is, that low boiling solvents such as dichloromethane or 1,2-dichloroethane are applicable at normal pressure. High molecular weight of the polyester is only obtained by the use of terephthalic and isophthalic acid chlorides of high purity.

With respect to mechanical properties we obtained the best results using a mixture of terephthalic and isophthalic acid chlorides within the range of a 1:1 to 3:1 mixture. Films cast from solutions of polyesters synthesized only with one of these two acid chlorides show brittleness.
The melting range of ISO-FPE is close to the heat distortion temperature at 480°C. Due to this fact and the high temperature resistance ISO-FPE is not suitable for injection molding and extrusion. ISO-FPE shows good mechanical and electrical properties over a wide range of temperature and frequency (see Fig 2). ISO-FPE is soluble in dichloromethane, chloroform, 1,2-dichloroethane, 1,1,2,2-tetrachloroethane, trichloroethylene, dimethylformamide, dimethylacetamide, cresol, tetrahydrofurane and methyl benzoate.

ISO-FPE is insoluble in water, acetone, methanol, ethanol, isopropanol, ethyl acetate and benzine.

Combustion of ISO-FPE coatings and films yields very low smoke and toxic gas generation. As shown in Fig 3 ISO-FPE produces some CO and CO₂, which are within the permitted ranges and no HF. The flame spread data according to ASTM E - 162 are given in Fig 4 and the smoke production in Fig 5. In both cases the film is compared with the data of a PVF film of same thickness.

Production of Powder and Films
After synthesizing ISO-FPE polyester in a laboratory scale we looked for a possibility to process the polyester in batches of some pounds. Therefore, a small pilot plant was developed to work with both the solution condensation method and the interfacial condensation method. This pilot plant is a sort of universal tool adaptable to the actual needs. The conditions of a small scale production could be studied with this machine. Now, batches of 40 pounds of polyester can easily be obtained in a second generation pilot plant. However, the preparation of pure, high molecular weight polyester demands a lot of tedious hand labour at the moment, restricting our output to one batch a week.

In spite of these and other difficulties we have been able to cast films in a continuous process on a laboratory film casting machine using a 200μ Teflon foil as substrate. Plans are under consideration for a pilot plant equipment with a production of up to 20 tons of polyester per year.

Currently films are available in thicknesses from 1/4 of a mil up to 3 mil. In addition preliminary studies have been conducted to evaluate the adhesive performance of various decorative inks on the film. The film may be embossed at temperatures between 100 and 180°C under a pressure of 290 psi using conventional pressing techniques.
The film can be pigmented with various inert inorganic pigments such as TiO₂ and various tinting agents and colorants. Furthermore, preliminary tests were conducted to evaluate the soil and smoke resistance according to Boeing standards which are shown in Fig 6.

As a conclusion we think that the ISO-FPE film has a potential use as a cost-effective fire resistant film for aircraft interior applications. However, additional work is required to evaluate this film in conjunction with current state-of-the-art aircraft interior panels and other advanced structures.

Thank you for your attention.
TGA of ISO-FPE

% weight retention

Nitrogen $\tau_{800} = 58\%$

Air

Thermogravimetric Analysis of ISO-FPE under nitrogen and air

Figure 3
## Properties of ISO-FPE

<table>
<thead>
<tr>
<th>Test</th>
<th>Average Value</th>
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<tbody>
<tr>
<td><strong>Powder</strong></td>
<td></td>
</tr>
<tr>
<td>Glass transition temperature</td>
<td>°C  none</td>
</tr>
<tr>
<td>Melting range</td>
<td>°C  none</td>
</tr>
<tr>
<td>Heat distortion temperature</td>
<td>°C 480</td>
</tr>
<tr>
<td>Inherent viscosity</td>
<td>dl·s⁻¹ 0.60</td>
</tr>
<tr>
<td>(phenol : tetrachloroethane = 60 : 40</td>
<td></td>
</tr>
<tr>
<td>0.5 g / 100 ml</td>
<td></td>
</tr>
<tr>
<td><strong>Film</strong></td>
<td></td>
</tr>
<tr>
<td>Thickness</td>
<td>mm 0.050</td>
</tr>
<tr>
<td>Density</td>
<td>g·cm⁻³ 1.22</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>Pa·10⁶ 662</td>
</tr>
<tr>
<td>Elastic modulus</td>
<td>Pa·10¹⁰ 0.21</td>
</tr>
<tr>
<td>Elongation</td>
<td>% 4.2</td>
</tr>
<tr>
<td>Dielectric strength</td>
<td>kV·cm⁻¹ 285</td>
</tr>
<tr>
<td>Dielectric constant</td>
<td>Hz 3.55</td>
</tr>
<tr>
<td></td>
<td>kHz 3.52</td>
</tr>
<tr>
<td></td>
<td>MHz 3.70</td>
</tr>
<tr>
<td>Dissipation factor</td>
<td>Hz 25.0 · 10⁻³</td>
</tr>
<tr>
<td></td>
<td>kHz 8.0 · 10⁻³</td>
</tr>
<tr>
<td></td>
<td>MHz 17.2 · 10⁻³</td>
</tr>
<tr>
<td>Volume resistivity</td>
<td>500 V Q·cm⁻¹ 1.0 · 10¹⁷</td>
</tr>
<tr>
<td>Surface resistance</td>
<td>1000 V Q</td>
</tr>
<tr>
<td>Weight loss after 24 hrs, 250°C %</td>
<td>1.48</td>
</tr>
<tr>
<td>Water absorption</td>
<td>% &lt; 0.5</td>
</tr>
<tr>
<td>Solder float test (250 °C) s</td>
<td>&gt; 120</td>
</tr>
<tr>
<td>Char yield r_b 800°C, nitrogen %</td>
<td>58</td>
</tr>
<tr>
<td>Limiting oxygen index film, 125 μ, room temp., vacuum</td>
<td>36</td>
</tr>
<tr>
<td>Rod (sintered at 220 °C under pressure)</td>
<td></td>
</tr>
<tr>
<td>Limiting oxygen index % R. 78</td>
<td>40</td>
</tr>
</tbody>
</table>
Toxic Gas Evolution of ISO–FPE–Film

<table>
<thead>
<tr>
<th>NBS Chamber</th>
<th>4.0 min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Film</td>
<td>0.001 inch Densil adhesive</td>
</tr>
<tr>
<td>3-ply laminate</td>
<td>(Ciba Geigy 971 G/1581)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Tedlar</th>
<th>ISO–FPE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.002 inch</td>
<td>0.002 inch</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>NOx, ppm</th>
<th>7</th>
<th>2</th>
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</thead>
<tbody>
<tr>
<td>CO</td>
<td>100</td>
<td>120</td>
</tr>
<tr>
<td>CO2</td>
<td>1800</td>
<td>1800</td>
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<tr>
<td>HF</td>
<td>102</td>
<td>0</td>
</tr>
</tbody>
</table>
Flame Spread Data of ISO - FPE - Film

ASTM E - 162

<table>
<thead>
<tr>
<th>Film</th>
<th>I s</th>
<th>S.D. x</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-ply laminate</td>
<td>2.65</td>
<td>0.60</td>
</tr>
<tr>
<td>0.001 inch Densil adhesive</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-ply laminate + 0.001 inch Densil adhesive</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.002 inch Tedlar</td>
<td>1.82</td>
<td>0.43</td>
</tr>
<tr>
<td>0.002 inch ISO - FPE</td>
<td>2.00</td>
<td>0.40</td>
</tr>
</tbody>
</table>

S.D. x  Standard Deviation

R. 79
Smoke Measurements of ISO - FPE - Film

NBS - Smoke Chamber 2.5 W/cm²

<table>
<thead>
<tr>
<th></th>
<th>Specific Optical Density (Flaming Condition)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dₙ</td>
</tr>
<tr>
<td></td>
<td>1.5 min</td>
</tr>
<tr>
<td>Tedlar 0.002 inch</td>
<td>6.67</td>
</tr>
<tr>
<td>ISO - FPE 0.002 inch</td>
<td>10.93</td>
</tr>
</tbody>
</table>

R. 79
Soil Resistance and Smoke Stain Resistance of

ISO-FPE-Film

Tested by Boeing Material Specification 8-220

Items: butter
mayonnaise
chocolate
soup
fruit stain (orange juice)
cigarette smoke (168 hours)

Washing agents: SU 126 STRO (Unilever) 10% solution
SU 904 JET (Unilever) 10% solution

ISO-FPE-Film (0.002 inch) shows no
discoloration when soiled and cleaned in
accordance with Boeing Material Specification,
Section 8.3. and 8.4.

R. 79
<table>
<thead>
<tr>
<th>NAME</th>
<th>AFFILIATION</th>
<th>TELEPHONE</th>
</tr>
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<tbody>
<tr>
<td>E. B. Mix</td>
<td>Boeing Aerospace Company</td>
<td>206-773-8009</td>
</tr>
<tr>
<td>R. A. Anderson</td>
<td>Boeing Commercial Airplane Company</td>
<td>206-237-9725</td>
</tr>
<tr>
<td>E. Bara</td>
<td>Boeing Commercial Airplane Company</td>
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<tr>
<td>J. P. Billington</td>
<td>Boeing Commercial Airplane Company</td>
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<td>T. E. Brandon</td>
<td>Boeing Commercial Airplane Company</td>
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<tr>
<td>F. J. Gorges</td>
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<td>S. A. Hasselbrack</td>
<td>Boeing Commercial Airplane Company</td>
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<td>P. J. Lester</td>
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<td>R. M. McLane</td>
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<td>206-433-1325</td>
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<td>S. R. Nemeth</td>
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<tr>
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<td>517-496-4606</td>
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<td>G. P. Bates</td>
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<td>L. H. Back</td>
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<td>213-354-3537</td>
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<td>C. P. Bankston</td>
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<td>J. Bellan</td>
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