Insulation for use within Rocket
Motors - A Survey.
(Bristol Aerojet)

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BANWELL, WESTON-SUPER-MARE, ENGLAND

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CONTENTS

INSULATION FOR USE WITHIN ROCKET MOTORS - A SURVEY

SUMMARY

A survey has been made of materials that have been considered or used as insulation for rocket motors during the past twenty years. The requirements for this type of application are discussed and illustrated mainly by reference to American practice. The results of a literature survey is presented and was made by combining relevant 'in-house' data with that from an ESA document Search by DRIC.

For convenience much of the information obtained has been summarised and is presented as seven appendices in the following way:-

Appendix 1	Summary of the ESA document search
2	Some typical American venturis and blast pipes
3	A summary of relevant Technical Reports from Bristol Aerojet Ltd.
4	Additional British data
5	Canadian data
6	Synopsis of 51 papers highlighted by the ESA Search
7	A survey of man made fibres

1. FOREWORD

Although it is hoped that this survey may have general utility, if only as a reference paper, its main purpose was to provide the background data needed in a programme which sought an alternative material to ashestos fibre. The main objective in this survey was therefore to ascertain from published data what other materials, and particularly fibres, have been used or considered for use as rigid and flexible insulations in rocket motors within roughly the past twenty years so that an appraisal might be made of their potential as alternatives for asbestos should legislation, or other factors, preclude its use at some future time.

2. REQUIREMENT FOR AN INSULANT

It is well known that the metallic materials from which rocket motors are usually made have to be protected against the effect of intense heat for short periods of time if the structure is to retain its strength and geometry and so be capable of performing its mission. Polymeric materials have been used, widely, to provide this protection as they are relatively poor conductors of heat and also absorb appreciable amounts of thermal energy as they pyrolyse. Under the environment of a rocket motor firing this decomposition occurs at an extremely rapid rate and is usually accompanied by unacceptably high erosion losses. These defects can, however, be partly mitigated by loading the polymer with suitable fillers, often of a refractory nature, and by accepting that an appreciable portion of the insulation will still ablate away as the motor fires.

Apart from being subjected to temperatures which can often be as high as 3500 K, the insulation may be in direct contact with the propellant and therefore must be compatible with it and not react chemically with it under world wide environments of use and storage; in addition there is often a need for the charge and insulation to be bonded together strongly so that burning cannot occur prematurely at this interface.

Density is a further factor affecting the choice of an insulant, because of its effect on payload, but as space within the motor case may also be at a premium, compromises may have to be made between the density of a material and its efficiency as an insulation in order to achieve a minimum acceptable thickness for the insulation.

3. SCOPE OF THE REVIEW

This report sets out to summarise the data that was available on rigid and elastomeric insulation that has either been used, or has been under consideration, for use in rocket motors essentially within a period spanning 1958 to about 1976; it has been confined to insulation used as protection against the effect of elevated temperatures and although cryogenic applications are important for liquid fuelled motors, they were not considered in the survey.

4. THE LITERATURE SEARCH

Two sources of literature were used but only 'unclassified' or 'restricted' material was examined. The first covered in-house references, abstracts and documents whilst the second still more comprehensive search used the ESA Documentation Service of Defence Research Information Centre (DRIC). The author is deeply indebted to Mr. Brian Clasby of this latter centre for his assistance in providing abstract print-outs from their data base and also to Mrs. S. Dibb of Bristol Aerojet who supplied the actual articles, papers and prints from microfiches etc., used in this Survey.

Appendix 1 is a brief resume of the basis for the DRIC search.

5. THE AMERICAN SCENE - THE U.S.A.

5.1 General

As might have been expected a considerable proportion of the relevant literature examined originated from the U.S.A. and reflects the importance they have attached to defence and attack missiles and to the exploration of outer space.

These latter applications involve mission times which are far in excess of those required even for inter-continental ballistic missiles and therefore need insulation to a standard which might have relevance to a future generation of rocket motors. Some idea of the exposures encountered in space flights can be obtained from Figs.1 and 2. Fig.1 summarises the temperatures that occur at various stages in the single mission of the Mercury capsule and lists some of the materials that were being considered for this project in about 1960.

More recently the concept of a space shuttle has introduced a need for insulation which cannot be met easily by the ablating types of insulation which have been used successfully for years on manned space flight projects. In this new application the vehicle will have to withstand repeated entries and exits through the earth's atmosphere so, ideally, to be economic, the insulation used should have the same life as the vehicle. An alternative but less economic solution of this problem will be to use 'one off mission' insulation which can,not only, be produced cheaply, but can also be replaced easily and quickly between flights.

5.1 contd.......

Some idea of the areas on a space shuttle vehicle that need protection and the temperatures they are expected to reach may be obtained from Fig.2 which summarises North American Rockwell's design requirements for their High Range Cross Orbitor Vehicle.

5.2 Types of Insulation that have been used

The survey has confirmed impressions that a wide range of thermal insulation has been and is currently being used in rocket motors. This range covers simple insulations such as sheet cork on Minuteman (to protect its structure during launch from its silo) or the laminated wood and metal structure of the nose cone of the second stage of the Polaris A3 missile, and extends to include difficult to produce and process materials such as refractory oxycarbides of zirconium, hafnium or tantalum etc. Various types of graphites either alone or in conjunction with high melting point metals such as tungsten and molybdenum are also being widely used in American rocket motor venturis especially in the arduous areas of their throats.

The majority of these insulants were developed up to 20 years ago but as Appendix 2 will show, they are still in current use on front line defence missiles and for outer space explorations.

A range of insulants is generally used in combination and Appendix 2 is introduced to show, by means of diagrams, the construction and location of the insulation within the nozzles of 13 well known American rocket motors or missiles. Nozzle construction has been selected for this purpose because their materials of construction, and especially the insulation, are usually subjected to the maximum effects of the combustion of the propellant. Between 65% and 75% of the total vehicle thrust develops within the throat of the nozzle as the chamber products accelerate to sonic velocities, with the balance of this thrust being developed within the expansion cone of the nozzle.

Although some of the nozzles shown in Appendix 2 are no longer in production, all of them that are used on missiles were still in current deployment in 1976; they range from the simple low cost nozzle used on the Sidewinder IC missile to the more complex movable nozzles that are used for achieving thrust vector control for the first stage of the Poseidon C3 missile.

In addition to these examples, Table 1 has been produced to provide a reasonably brief summary of past and current American applications for temperature resisting materials in their rocket motors.

5.2 contd.......

For convenience, American terminology is used in this table and is based on the following definitions:-

A THERMAL LINER	Material which forms the aerodynamic contour with its surface directly exposed to the exhaust of the burning motor.
AN INSULATOR	Is a material placed behind a liner to serve as a thermal barrier to prevent the underlying structure from reaching an excessive and unacceptable temperature. Sometimes a single material can serve as liner as well as insulator and in some instances can also form the structure.
THROAT INSERT	Is a special erosion resistant liner placed in the throat region of a nozzle to keep increases in its diameter by erosion losses at a minimum.

6. EUROPEAN PRACTICE

Apart from the possibility of a language barrier problem causing a low abstraction from Continental literature, the survey showed that there has been much less publication of relevant information in Europe than in America. In particular any useful detailed data on practice in the USSR was not obtained from the survey. An impression has, however, been formed that the rest of European practice resembles or even follows American techniques closely despite its general lower funding.

In Great Britain the Ministry of Defence has sponsored work at Bristol Aerojet Ltd., on a variety of insulants so a digest of related reports has been prepared to form Appendix 3 of this report. This appendix spans the years 1968 to 1977 and presents data in the following way:-

Moulding compounds for compression, transfer or displacement moulding	One component filler Combinations of fillers	Sheets 1-3 Sheets 4-5
Other insulation topics	Edgewise tape winding Glass fibre overwinding Carbon cord/asbestos tape. Asbestos/carbon end plates. Silicone nitride Elastomeric compounds	Sheet 6 Sheet 5

Appendix 4 contains a summary of other data from U.K. sources.

7. CANADIAN PRACTICE

Some brief comments of the Canadian scene is introduced as Appendix 5, because of an early use, there, of cast in situ linings.

8. GENERAL FINDINGS

Appendix 6 contains a brief synopsis of 51 papers highlighted by the literature survey and which are thought to be of relevance to the purpose of this report. Materials that are mentioned in this Appendix, and which could be considered when planning development work on insulation, include:-

		Appendix 6 Item Ref.
Rigid Composites	Carbon-carbon	14, 50, 51.
	with additives e.g. inhibitors	35, 36, 46.
	Borides	31, 32, 33.
	Quartz-phenolic	48.
Fibres	Alumino silicates from Carborundum Co.	47
	Mullite fibres	46
	in combination with Kaowool	46
	Magnesia fibres	23
Foams	Ceramic foams	45
Elastomerics	DC-93-104 proprietary material	43, 49.
	Dual layer insulation	39
Miscellaneous	Addition of ammonium salts, (e.g. sulphate, benzoate), or potassium titanate to moulding compounds and elastomers.	28
	Pyrocarbide formation	40, 41.
	Deposition of films onto insulants by plasma spray.	22.

9. MAN MADE FIBRES

A general survey based on information available about these types of materials, and which have either been applied in insulation or could be considered for this purpose, is given in the two sheets that form Appendix 7. This data is presented in the following way:-

Sheet 1 and 2 - Sheet 1 details information about alumino-silicates produced directly from naturally occurring minerals; Sheet 2 gives data about known syntheses of silicates.

Sheet 3 - Lists the other types of man made fibres that have or could be considered for use in insulation and for the sake of completeness includes the well known glass, carbon and nylon fibres.

10. CONCLUSIONS

Although it is difficult to provide well defined conclusions from a summary of this type, several opinions have been formed; they are:-

1. The predominance of literature found was of American origin and although funding of work on rocket propulsion has been greater than elsewhere, it would appear also that their work has received wider publication than comparable UK and European research.

2. There seems to have been a considerable reduction in the rate of progress in the USA since about 1968 and many of the insulants used in the motors of currently deployed missiles were developed much earlier.

3. Although many materials which have been developed in the USA have also received attention in the UK, practical evaluation here, by actual or closely simulated rocket motor firings, has lagged behind USA practice.

4. Some of the American development has been with relatively sophisticated materials but UK references to any work with such materials were not found.

5. There are a few refractory fibres, e.g. mullites and various other aluminas which do not appear to have been examined in the UK for rocket motor applications.

6. Carbon/carbon composites have been reported to be promising insulants especially for space shuttle applications and are being developed in America for this use because existing ablative insulation is thought to be inadequate for such applications.

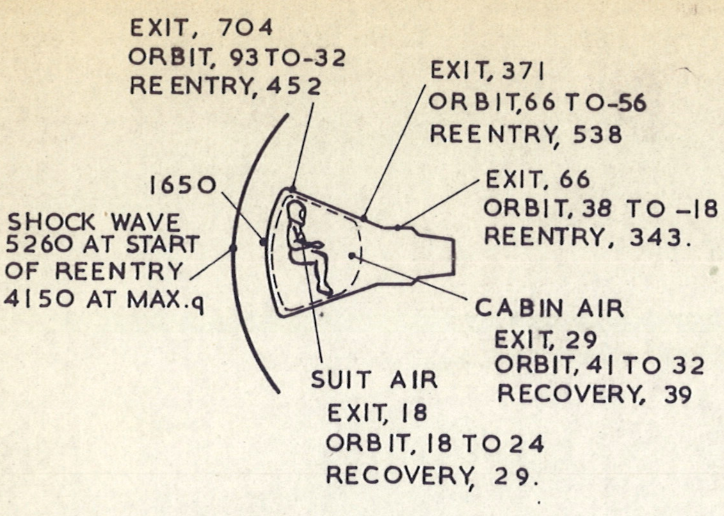
Phenolic resin combined with reinforcing materials such as carbon, graphite, silica, asbestos, or glass has been used extensively with success and can be regarded as the standard lining for most nozzles. Epoxide resins are less widely used although there are several examples of overwrapping with prepregs of these resins and can sometimes be attractive because they do not involve high pressure in their curing proceedures. Epoxy novolac resins have been used for this reason.	CLOTHS AND FABRICS	**Graphite/phenolic** **and** **Carbon/phenolic**	Both materials are used regularly as flame barriers for lining blast tubes, throat approaches and throat extensions, i.e. immediately upstream and downstream of the throat, and are used almost exclusively in these locations when the throat diameter exceeds about 250 mm. Graphite cloth/phenolic is preferred whenever erosion will be severe and whenever thermal stability is important and has been used almost exclusively on the very large motors of recent time. The lower cost and lower thermal conductivity of carbon cloth can make it attractive because thinner sections can be used and back-up insulation may not be needed. Either type of material has especial application if condensation and deposition from exhaust products on to the thermal surfaces of the nozzle ('slagging') can occur shortly after ignition when these surfaces are still cool (such deposition can change the aerodynamic contours, alter the heat transfer into the lining and may introduce an irregular thrust trace; it can also lead to an unsatisfactory function of movable nozzles. Stacked layers and rosette lay-ups are widely used with a stacked layer often being built up in conical form from individual patterns cut from prepregged broad goods, as angles greater than 15^{0} to the axis can be obtained easily in this way. Rosette or petal lay-ups, also with precut patterns, allow edge orientations to be presented to the gas flow so that a portion of each individual petal may remain unaffected by the firing.
		Silica/phenolic	Often used when the expansion ratio is between 2 and 4 because it is cheaper than either graphite or carbon cloth; it has even been used as a throat lining for short burning time motors (<10s) which do not develop pressures much above 100 lb in^{-2} and which use either a low flame temperature propellant (<2700^{0}C), or a highly oxidising one. Silica/phenolic material is sometimes also used to insulate the vulnerable areas of a steel motor case and quarter circumferential mouldings are bonded into forward and aft closures and/or to wing rings for this purpose.
		Asbestos/phenolic **Glass/phenolic**	The main application is as 'back-up' insulation behind highly thermal conductive liners such as pyrolytic or polycrystalline graphite. There are some examples of asbestos/phenolic being used as the throat lining of nozzles on short burn time, low flame temperature motors where its low cost is attractive. Glass/phenolic is widely used on large nozzles as 'gore strips'. In this weight saving application triangular shaped cut outs the length of the cone, are laid flat along the exterior of the liner/insulation combination and are then overwound with a glass roving or tape at each end. There are also a number of examples, but mainly in outer space activities, where glass/phenolic material has been used as the main structure (of HS 303 A satellite motor of Sheet 28 of Appendix 2.) Both materials, together with silica/phenolic, have widespread application as the only insulation of areas of low erosion, such as the aft portions of exit cones. Their low cost and relatively low density has also made them attractive for use as materials of construction for the exit cones of massive rocket motors such as a NASA solid propellant alternative for their Saturn project.
	TAPES	Carbon/phenolic Graphite/phenolic Silica/phenolic Asbestos/phenolic Glass/phenolic	All these materials are used either independently or in combination as a more economic way of using fabric especially for nozzles having a diameter greater than 16 inches. Composite liners are produced by overwrapping debulked inner linings with a tape insulation and then curing the two materials in one operation. Any type of tape can be applied 'straight' i.e. cut parallel to the weave pattern - or 'bias' so that cutting is at an angle to this pattern. Most tapes are used as prepregs. There are many examples (see Appendix 2) of their use to produce basic structure when a light weight construction is essential but glass/phenolic tapes seem to have been exploited more in this way than the others, possibly because of their low cost and earlier availability.

TABLE 1 - A SUMMARY OF AMERICAN PRACTICE

GRAPHITES	BULK OR MONOLITHIC FORMS	Polycrystalline graphite	General application is for nozzles of < 8 inch throat diameter and is attractive because up to about 2500°C the strength increases with temperature rise. Components are produced either by compression moulding or extrusion. Main application is where a low cost material with high resistance to erosion is needed as in throat approaches, throat extensions and blast pipes. Often used in the throat itself but then usually in combination with a high melting point metal, e.g. tungsten or molybdenum - insert in the hottest areas; there are, however, several small motors where it is the only insulation and forms the throat. (cf Sparrow nozzle - sheet 18 Appendix 2). The main problem experienced is its relatively brittle nature which can lead to spiral crack propagation especially during the initial firing stages; but this problem can sometimes be overcome by segmenting the liner in the areas of incipient cracking or by using it in ring or washer form.
		Pyrolytic graphite Pyrolytic graphite/ infused with silicon carbide.	Used whenever the erosion resistance and/or the strength of polycrystalline graphite is inadequate. Frequently used as a stack of washers with the thickness of an individual washer not exceeding $\frac{1}{8}$ inch but with a tight thickness tolerance being specified only for the assembled and compressed stack. Main drawback is the material's high thermal diffusivity which usually results in a need for backing insulation.
	PYROLYSED REINFORCED PLASTICS	Carbon/carbon composites. (the reinforcement can be a fabric, fibres or a felt of either carbon or graphite)	Becoming more widely used because of its high efficiency and light weight. Recent project applications have included the nozzles of SRAM (Lockheed Propulsion solid fuelled motor for a short range attack air to ground missile) and Trident 1, C4 missile where it is being used as stacked rings. This use of rings is common and they have been used fore and aft of pyrolytic washers which form the throat. Materials of density around 1400 kg m^{-3} have been used mainly to date, because of availability but densities of 2000 kg m^{-3} are now available and have better resistance to erosion. In this density it is now often preferred to plycrystalline graphite and is rapidly replacing carbon/phenolic and graphite/phenolic lining in nozzles which have throat diameters > 8 inch despite its much higher cost. There seems to be two main manufacturing techniques:- (i) Chemical vapour deposition of pyrolytic carbon, from vapour, into the reinforcement. (ii) Impregnation of the reinforcement with liquid resin and/or pitch, followed by carbonisation. This process is repeated several times until the required density is achieved. The material is then pyrolsed finally at 2482 - 2760°C (4500 - 5000°F) to graphitise the matrix carbon partially. Centres of expertise in these techniques exist at Sandia Laboratory, Alberquerque, N. Mexico, Supertemp Co., Santa Fe Springs, Calif, Lockheed Aerospace and many others. A wide range of matrix resin(s)/impregnants have been described and there are several techniques for applying them.

TABLE 1 (cont'd)

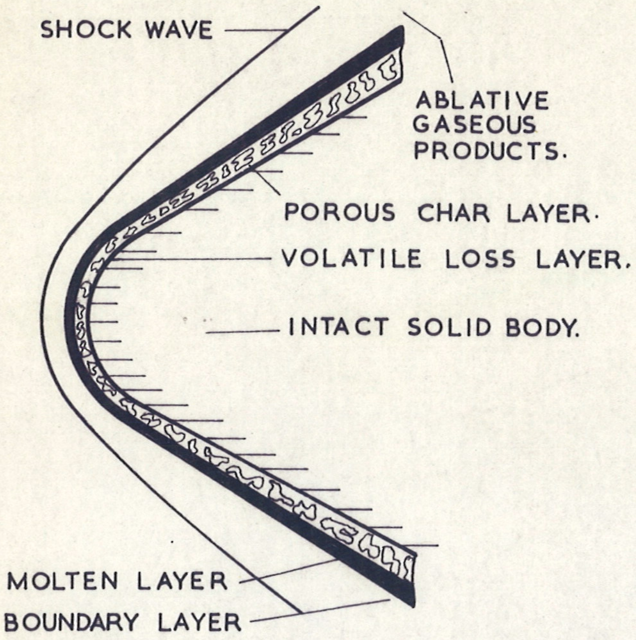
ELASTOMERS	Sheet or Mouldings	Although there has been past usage of elastomers as linings in nozzles, they have been confined to regions of low mach number (0.2) where erosion is not a serious problem. Typical example have been the larger end of convergent-divergent nozzle inlets or on the chamber side of submerged nozzles; they have also been used to provide flexible sealing on movable nozzles. The major application has been for heat and pressure cured materials produced by compression or autoclave techniques, and containing either chopped fibres or powders of carbon, silica or glass, used either alone or in combination. Butadiene acrylonitrile formulations were widely used as cast lining and several types of silicones have also been used where higher temperature resistance has been required. 'O' rings are widely used between components to prevent gas flow and also to prevent non bonded areas from becoming pressurised. Low temperature exposure, such as on outerspace vehicles, has often inhibited the use or restricted the choice of compound.
	Castables	It is known that at least two project motors have their internal insulation applied by a casting/spinning technique in which the cases are spun at relatively slow speeds in a vertical position to deposit a liquid rubber preparation on to the closure areas; different speeds, (three are common) are used to contour the thickness spread and with some degree of cure being applied between each coating. The insulation on the parallel portion of the motor is then applied by spinning the motor in a horizontal postion (somewhat similar techniqueshave also been developed by DREV at Valcartier in Canada).
REFRACTORY MATERIALS	Metals	Molybdenum and tungsten and its alloys are widely used as throat inserts to achieve the minimum possible erosion losses in this critical area. Tungsten or its alloys in forged extruded or in pressed and sintered forms are used more widely in this way than molybdenum; forgings and extrusions are, however, preferred, despite their higher cost, for higher flame temperatures but silver and copper infiltered tungsten are preferred when still higher temperatures of 3316 - 3593°C (6000 - 6500°F) have to be resisted. The current limitation of application seems to be at a 7.5 inch throat diameter. Throat linings produced either as forms or as surface coatings by flame spraying these metals, have been used, although not widely. It seems to be general practice to coat the faces of tungsten inserts which may be in contact with carbonaceous materials to prevent the formation of eutectics so thin films of tantalum metal or thoria are commonly applied.
	Ceramics	Generally considered in the past to be too brittle for most missile applications but the main insulation of the Bullpup missile case was of this type. There have been frequent literature reference to investigations of ceramics, simple as well as complex, for use in missiles as insulation, often as linings for nozzle throats. Ceramics and foamed ceramics are being used in current designs of space shuttle vehicles as one solution of the problem of providing insulation which can withstand repeated re-entry conditions. (Fig.2 of this report shows the temperature pattern of such a vehicle). END



REPRESENTATIVE TEMPERATURES FOR MERCURY SPACE FLIGHT CONDITIONS.

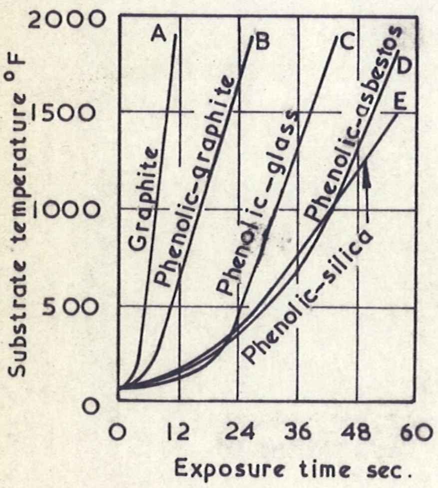
Figures are estimated °C

(This figure appeared originally in a paper by S. Speil. Johns-Manville Research & Engineering Center, Manville. N. J.)



Ablating plastic composite during the re-entry heating. (Glass-fibre-reinforced phenolic resin served as the ablating model)

(All these figures appeared originally in a paper by D.L.Scmidt. Modern Plastics. Nov. 1960.)



Substrate temperatures in various ablating materials. Test facility: Electric air arc; Initial flux: 400 B.t.u./ft^2 sec; Thermocouple: 0·25 in. from original stagnation point.

ABLATING MATERIALS THAT WERE BEING CONSIDERED IN 1960 FOR MERCURY SPACE FLIGHT MISSIONS.

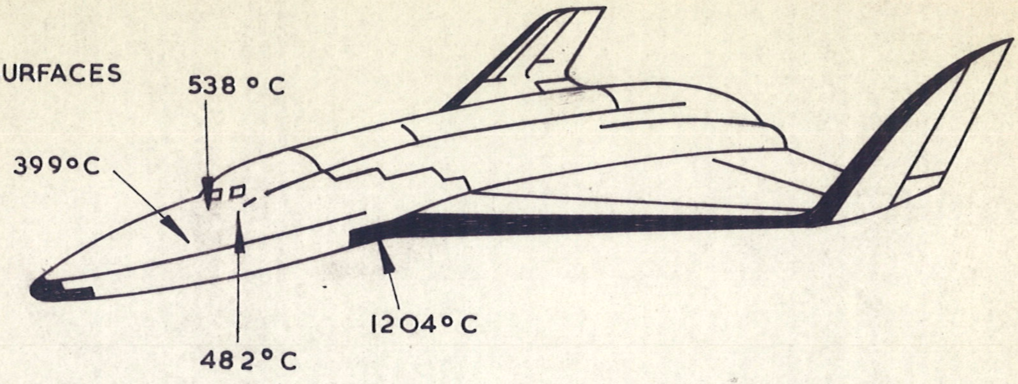
Linear ablation of various materials in high temperature air (15). Test facility: 1 megawatt electric arc; Gas composition: air; Gas enthalpy: ~8000 B.t.u./lb; Gas temperature ~15-1000°F (-9-538°C); Gas velocity: 2500 ft/sec; Initial heat flux: 1950 B.t.u./ft^2 sec; Exposure duration: 30 seconds.

SA10099

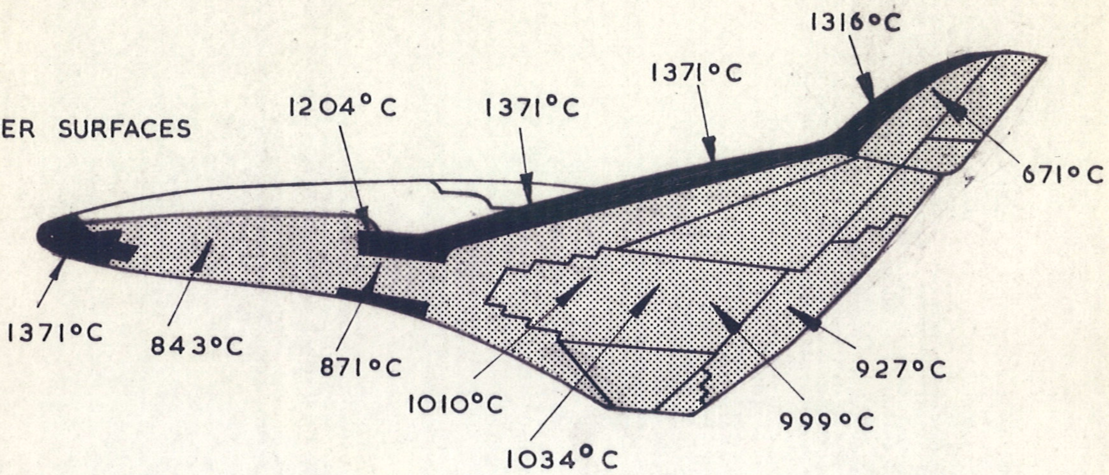
SPACE FLIGHT CONDITIONS.

This figure appeared originally
in SAE Preprint No. 700771
"Development of non metallic external
insulation thermal protection systems
for space shuttles."

UPPER SURFACES



LOWER SURFACES



FLIGHT CONDITIONS		REQUIREMENTS	CANDIDATE MATERIALS
■	ABOVE 1093°C (2000°F)	High temperature properties.	Reinforced pyrolysed plastics eg: carbon/graphite composites.
□	BELOW 1093°C	High temperature properties. Minimum weight Resistance to oxidation Cost. Satisfactory margin of reserve performance.	Any re-usable external insulation which will withstand temperatures up to about 1000 °C.

SA 10100

SHOWING WHERE THERMAL PROTECTION SYSTEMS WILL BE NEEDED ON THE NORTH AMERICAN-ROCKWELL HIGH CROSS RANGE ORBITER

APPENDIX I

APPENDIX I

SUMMARY OF ESA DOCUMENTATION SERVICE SEARCHES

Three searches were made with each, in turn, becoming more selective.

Search No.1

In this initial broad search a wide range of descriptors was used, which in the event were insufficiently discriminating. For example the word 'insulation' recalled data concerned with refrigeration as well as too wide an application of insulation against heat despite its modification by 'rocket motor'.

The search programme provided by ESA is attached as Table 1.

Despite these limitations, useful abstracts were found amongst the 105 printed out, they include examples such as

(i) Role of silica and quartz phenolics in ramjet engines

(ii) Fundamental studies on the nature and properties of ceramic fibres

(iii) Flexible thermal insulation for use in heat shields

(iv) Metallic ceramic composite insulating coatings on cooled hydrogen-oxygen rockets

(v) Mineral filled fibrous composites. New family of refractory products

(vi) Many other, some of which are already known and available at Banwell.

Search No.2

More selective descriptors were used in this next search to give 54 further abstracts. The search programme which is attached as Table 2, gave further useful data.

Search No.3

For this further and final search carried out the sets employed were reduced selectively to 22 as shown in the ESA programme that appears as Table 3 to this appendix. By this means a further 134 abstracts were obtained.

The total number of abstracts produced for scanning by these three surveys was therefore 293. (Defence controlled literature was not included in any of these surveys).

Complete articles, or microfiches where available, were then obtained on the basis of these abstracts and many of them have been summarised as Appendix 7 of this report.

APPENDIX 1

TABLE 1

FIRST E.S.A. SEARCH

SEARCH HISTORY

Set	Items	Description
1	0	BCC FILE 2 77-337
2	1278	NONMETALLIC
3	450	E6-E8, E10-E14 NONMETAL
4	8134	E6-E16 FILL
5	2	(2+3)*4
6	21903	THERMAL
7	17355	THERMAL (80)
8	2356	E8, E13 THERMAL
9	9830	E2-E10 INSULATION
10	1302	9* (6+7+8)
11	43	10 * 4
12	2226	ASBESTOS
13	2	ASBESTOS
14	46	E6, E7 CROCIDOLITE
15	2241	12+13+14
16	43	11 - 15
17	334	MATRICES
18	5392	MATRIX
19	828	MATRIXES
20	4	(2+3) * (17+18+19)
21	1254	10 - 15
22	48	21 * (2+3+4+17+18+19)
23	1178	E6-E9 ROCKET
24	8	23 * 21
25	13753	SILICA
26	46	21 * 25
27	101	22+24+26
28	1153	21 - 27
29	20502	GLASS
30	9449	GLASS (83)
31	121	21 * (29+30)
32	11331	E6, E9 CERAMIC
33	79	21 * 32
34	55	16+24+99
35	226	26+31+33
36	213	35 - 34.

Key:
- exclude
+ or
* as well as

APPENDIX 1

TABLE 2

SECOND E.S.A. SEARCH

SEARCH HISTORY

Set	Items	Description
1	0	BCC FILE 1 77-337
2	355	ABLATING MATERIAL
3	37	ABLATING NOSE CONE
4	1678	ABLATION
5	719	ABLATIVE MATERIALS
6	137	ABLATIVE NOSE CONES
7	850	HEAT SHIELDING
8	201	REENTRY SHIELDING
9	1098	REENTRY VEHICLES
10	58	ROCKET NOSE CONES
11	1241	SHIELDING
12	78	NOZZLE INSERTS
13	121	PYROLYTIC MATERIALS
14	1301	REFRACTORY MATERIALS
15	326	THERMAL CONTROL COATINGS
16	1149	THERMAL PROTECTION
17	631	RIGID
18	2150	E6 - E8 INSULATION
19	1523	THERMAL INSULATION
20	215	ASBESTOS
21	5056	COMPOSITE MATERIALS
22	267	LININGS
23	2434	PROTECTION
24	15	NOZZLE INSERT
25	34	NOZZLE WALL
26	119	NOZZLE WALLS
27	2928	E6, E18 NOZZLE
28	76	E6, E7 END PLATE
29	23	LINING
30	51	ROCKET LININGS
31	110	CASING
32	61	INSERTS
33	51	SHEATHS
34	227	E5, E6 NONMETALLIC
35	7436	E7, E10, E11 HIGH T
36	551	HIGH TEMPERATURE MATERIAL
37	2445	2+3+4+5+6
38	3276	7+8+9+10+11
39	1956	37 - 38
40	2	17 * 19
41	2	17 * 18
42	57	19 * (35+36)
43	4994	11+12+22+24+25+26+27+28+29+30+31
44	32	43 * 19
45	6	44 * 42
46	44	39 * 19

Key
- Exclude
+ or
* as well as.

APPENDIX 1

TABLE 3

THIRD E.S.A. SEARCH

SEARCH HISTORY

Set	Items	Description
1	0	BCC FILE 6 77-337
2	676	THERMAL INSULATION
3	208	ASBESTOS
4	208	ASBESTOS
5	150	HEAT SHIELDING
6	23	REENTRY SHIELDING
7	436	RIGID
8	1472	HIGH TEMPERATURE
9	168	ROCKET NOZZLES
10	2	DUAL THRUST NOZZLES
11	1847	R3-R15 ROCKET NOZZLES
12	7	2 * 7
13	231	4+6
14	666	2 - 13
15	1145	REENTRY
16	647	14 - 15
17	12	16*8
18	1847	9+10+11
19	9	16*18
20	506	E6-E10 ABLATION
21	33	18*20
22	54	17+19+21

Key

- exclude

+ or

* as well as

APPENDIX 2

APPENDIX 2

SOME TYPICAL AMERICAN VENTURIS AND BLAST PIPES

FOREWORD

The information contained in this appendix was abstracted from a NASA document on design criteria for solid rocket nozzles - NASA SP 8115 published in June, 1975.

Each of the three sheets of diagrams that form this Appendix has a separate sub-sheet outlining the main features of each venturi and the way it is insulated.

The following considerations apply throughout these sheets.

Polycrystalline graphite - are fine grade bulk or monolithic graphites produced either by compression moulding or extrusion.

Carbon, silica, asbestos or glass phenolic tapes - After consolidation by rolling, tapes are usually moulded in a hydroclave typically at 1000 $lb.in^{-2}$ for about 2 hours at 154°C (310°F). These tapes may be either straight tapes or can be bias cut when the plying at a high angle to the centre line, whilst remaining planar, is needed.

Graphite phenolic washers - are produced from pyrolsed graphite.

Mouldings of

graphite-phenolic
silica - phenolic
asbestos-phenolic - are all die moulded parts, made typically under a 2000 $lb.in^{-2}$ pressure; they may be produced from moulding flocks but the original reference did not give this information.

Two basic nozzle configurations are shown. The first is the classical convergent-divergent de Laval nozzle fitted externally to the combustion chamber but in the second, part or all of the exit is cantilevered into the combustion chamber either to reduce the overall length of the motor or, to use space more effectively in volume limited systems. A submerged nozzle is generally more complex in construction because much of its external surface is also subjected to the hot gases.

Apart from this difference in location the exit configuration can be either a simple truncated cone or may be contoured to turn the exhaust flow so that the gases exhaust in a more axial direction than would occur with the conical arrangement. Contoured exits, therefore, give the lower divergence losses but as might be expected usually result in an increased erosion of the liner forward of the exit plate.

Some details are given on sheet 4 about the missiles, their purpose and size on which the nozzles shown in Sheets 1 and 3 are used. This data has been abstracted from Janes Weapon Systems 1977 Pub. Janes Year Books, London.

contd...... from sheet 5

<table>
<tr><th>Construction</th><th>Report Reference</th><th>Synopsis</th></tr>
<tr><td>EDGEWISE TAPE</td><td>BAJ-TR.527-1970</td><td>This report summarises developments on this topic at Banwell; it concludes that on value analysis the most appropriate application is for producing components only when the performance achieved is advantageous or where the components produced would require large capacity presses and the use of expensive tooling. Amongst the advantages cited is its suitability for 'one-off' or prototype productions, and emphasises that both design and the manufacturing parameters are of the utmost importance for achieving a successful job.</td></tr>
<tr><td>OVERWINDING BLASTPIPES AND NOZZLES WITH GLASS FIBRE</td><td>BAJ-TR.571-1971</td><td>Reviewed the glass overwinding of nozzles and blast pipes and suggested that there was considerable evidence that a phenolic impregnating resin should replace the epoxide system which had been in use for roughly ten years. Twenty two instances of overwinding were cited and included the following projects.
<table>
<tr><th>Expansion Cone</th><th>Tail pipe</th><th>Tail pipe/ expansion cone</th><th>Venturis</th><th>Swivelling nozzles</th><th>Blast pipe</th><th>Submerged nozzles</th></tr>
<tr><td>Blackcap
Contraves motor
Cuckoo II
Kestrel
Pheasant
Phoenix
Raven
Rook
Stonechat</td><td>Falcon
Magpie</td><td>Linnet
Siskin LWT</td><td>Kestrel HWT
Wagtail</td><td>Linnet</td><td>Phoenix
Ladybird
Several test motors</td><td>Waxwing</td></tr>
</table></td></tr>
<tr><td>CARBON CORD/ ASBESTOS TAPE COMBINATIONS</td><td>BAJ-TR.709-1974</td><td>Small bore blast pipes were produced experimentally. These components were made by wrapping a custom made cord produced from Type III continuous carbon fibre roving around a steel mandrel consolidating and curing it before overwrapping it with several layers of preimpregnated Fortex asbestos tape. The whole assembly was then recured to give the final component ready for machining to length etc.</td></tr>
<tr><td>ASBESTOS/CARBON FIBRE COMBINATIONS</td><td>BAJ-TR.630-1972</td><td>Development of a high performance non metallic, light weight rocket nozzle is described. The carbon fibre materials considered included aligned short staple carbon fibre felts produced by PERME at Waltham Abbey and continuous carbon fibre filament tows.
The initial design based on the Lapwing nozzle assembly indicated a possible 30% weight saving; its production demonstrated that a careful orientation of the fibres, so that they were subjected to the applied stresses in the best possible manner, could lead to a component which was capable of fulfilling the structural requirements of this end plate.</td></tr>
</table>

End of Appendix 3.

THE MAIN FEATURES OF THE NOZZLE DESIGNS ON SHEET 2B ARE

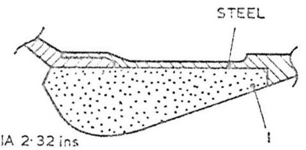
ALL ARE SUBMERGED NOZZLES

601-1 ORBITAL BOOST	A simple small diameter nozzle utilising polycrystalline graphite in the throat area and a carbon/phenolic tape elsewhere as the insulation.
APOGEE MOTOR HS 303A SATELLITE	Metal weight has been kept low and has been reduced to a minimum by the use of aluminium alloys. The throat is a carbon/phenolic moulding with an insert of tungsten in its critical area to reduce erosion to almost zero. The exit is contoured instead of having the usual truncated cone form and is insulated by a glass cloth/epoxide lining.
ASROC EXTENDED RANGE	Has thrust vector control by liquid injection into this exit cone. The main insulation is a silica/phenolic moulding with an insert of polycrystalline graphite in the throat area.
SURVEYOR MAIN RETRO ROCKET	Is a further lightweight design for a long burning motor having a throat insulation made up of a carbon fabric/phenolic resin rosette lay-up containing a polycrystalline graphite insert. The main structure is a glass/phenolic resin lamination around a carbon phenolic moulding reinforced locally by a glass epoxide filament winding; parts of it are also wound externally with an asbestos/phenolic tape.
260 SL 3 DEVELOPMENT MOTOR	In 1965 this was one of the largest diameter nozzles that had been built and tested. This nozzle is a complex lay-up of phenolic impregnated tapes produces from carbon, silica or glass with the carbon tape being used as the primary insulant. A silica/asbestos fibre filled NBR rubber is also used at the head end region of the motor.

KEY TO INSULATION

OPERATING CONDITIONS

SPARROW MK 38 MOD.1

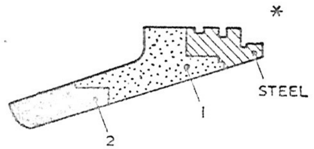


THROAT DIA 2·32 ins
THRUST 7085 lb in^{-2}

1 Polycrystalline graphite

Flame temp.	2950°C
Burning time	3·04 secs
Max. pressure	1280 lb in^{-2}

SIDEWINDER 1C

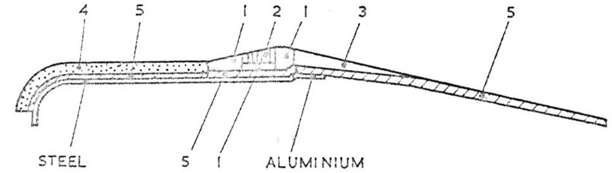


THROAT DIA. 1·67 ins
THRUST 2700 lb in^{-2}

1 Asbestos/phenolic moulding
2 Polycrystaline graphite

Flame temp.	2816°C
Burning time	5·21 secs.
Max. pressure	1500 – 2000 lb in^{-2}

PHOENIX MODEL 60 MOD.0

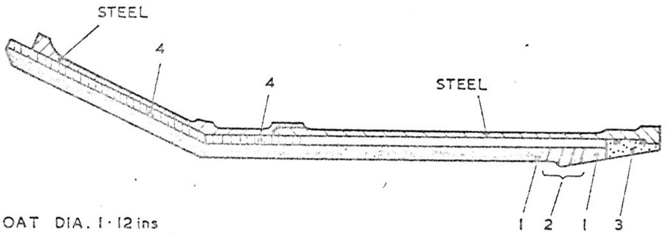


THROAT DIA. 2·18 ins
THRUST 1000-5000 lb in^{-2}

1 Polycrystalline graphite
2 Pyrolytic graphite washers
3 Carbon/phenolic tape
4 Carbon/phenolic moulding
5 Silica/phenolic tape

Flame temp.	2980-3149°C
Burning time	20–30 secs.
Max. pressure	700 – 1000 lb in^{-2}

CONDOR



THROAT DIA. 1·12 ins
THRUST 0-1000 lb in^{-2}

1 Polycrystalline graphite.
2 Pyrolytic graphite washers
3 Silica/phenolic moulding
4 Asbestos/phenolic moulding.

Flame temp.	2982 – 3149°C
Burning time	100 – 200 secs
Max. pressure	700 – 1000 lb in^{-2}

ALL THESE MOTORS
ARE FUELLED WITH
AP/PBCT/AI
PROPELLANT.

*SUBMERGED NOZZLE

All the diagrams in this appendix appeared originally in June 1975 in NASA DESIGN CRITERIA SP8115 'Solid Rocket Motor Nozzles.'

THERMAL INSULATION MATERIALS AND THEIR LOCATIONS IN VENTURIS/BLASTPIPES OF AMERICAN ROCKET MOTORS

APPENDIX 2

MAIN FEATURES OF THE NOZZLE DESIGNS ON SHEET 1B ARE

SPARROW MK 3B Mod.1	Possibly the simplest design in use in which the polycrystalline graphite is retained within a steel shell which itself forms part of the rocket motor case.
SIDEWINDER 1G	Is a simple submerged nozzle which uses polycrystalline graphite as the insulation for the more arduous areas and a resinated asbestos moulding in the final exit areas.
PHOENIX MODEL 60 Mod.0	Although this is a relatively small nozzle it is complex and comprises a blast pipe which is integral with the nozzle. Polycrystalline graphite is used in bulk and also as washers, and phenolic resin impregnated tapes of both carbon and silica are also used. The blast pipe lining is produced from a carbon/phenolic moulding material.
CONDOR	The nozzle and bent blast pipe are integral. Polycrystalline graphite is the main insulation but has to be replaced by pyrolytic graphite, in the form of washers in the throat to reduce the erosion that would otherwise occur in this critical area. Both types of graphite are backed by a resinated asbestos layer between them and the shell. The exit cone insulation is moulded from a silica/phenolic compound.

APPENDIX 4

<table>
<tr><th></th><th>Reference</th><th></th><th>Synopsis</th></tr>
<tr><td>1966</td><td>RPE Report 66/6
(R. Lister)</td><td>Comparison of thermal insulation for solid propellant rocket motors</td><td>A number of insulants were evaluated as linings for blast pipes and end plates by static firing in the end burning 203 mm SC test motor at Westcott.
All the carbon wool/phenolic, carbon wool/graphite/phenolic and silica/phenolic mouldings tested had better resistance to erosion than resinated asbestos but the latter's resistance was improved if it was used as an edgewise tape so that its fibres tended to be orientated more normally than usual to the gas stream. Two silica/phenolic materials were examined, one being moulded from flock and the other from dicings of a prepregged fabric.
Components wound from carbon or silica strings were superior in the firings to those made from asbestos string.</td></tr>
<tr><td>1967</td><td>SRS Report 67/19
(M. J. Chase)</td><td>Visit to Allegeny Ballistics Laboratory during USA tour.</td><td>Asbestos/phenolic materials were considered to be reliable insulation so further development was not necessary.
Rubbers containing 30 pphr of asbestos were in use as case linings and it was believed that, in a firing, the asbestos acted as a cracking catalyst to ensure the production of long chain products from the pyrolysis of this insulant.
Silica, nickel powder and nickel acetate were also thought to have a similar effect during this pyrolysis.</td></tr>
<tr><td>1967</td><td>RPE Tech. Memo 446
(A. C. Parmee)</td><td>Material Developments for rocket nozzles.</td><td>High energy aluminised propellants were limiting the choice of materials for nozzles but graphites, tungsten and refractory carbides were attractive. Pyrolytic graphite was excellent for this purpose also, and had markedly improved resistance to erosion (up to 20 fold better) over other forms of graphites; it was satisfactory for free standing shells as well as stacked disc designs. Pyrolytic graphite compared favourably with Tungsten.</td></tr>
<tr><td>1972</td><td>Manchester University
MSc Thesis
(D. Kershaw)</td><td>Ablation Studies of Composite Materials</td><td>Oxy acetylene torch tests were made using a rig designed and made by the author for examining tubular specimens with a ¼ inch thick wall, 9 inches long, 1½ inch o/d. All testing was carried out with a neutral 1:1 gas mixture. Some test results obtained were:-
<table>
<tr><th></th><th>% wt loss</th><th>Char Yield TG 900°C</th><th>Fibre content % wt</th><th>S.G. kg m -3</th></tr>
<tr><td>Silica/phenolic</td><td>18.8</td><td>77.6</td><td>58.0</td><td>1670</td></tr>
<tr><td>Kaowool/phenolic</td><td>19.5</td><td>83.4</td><td>68.4</td><td>1840</td></tr>
<tr><td>E-glass/phenolic</td><td>19.7</td><td>80.4</td><td>66.8</td><td>1840</td></tr>
<tr><td>Asbestos/CS.203 phenolic</td><td>23.7</td><td>73.4</td><td>63.2</td><td>1800</td></tr>
<tr><td>Asbestos/Xylok 210</td><td>23.7</td><td>70.5</td><td>60.1</td><td>1710</td></tr>
<tr><td>Durestos RA.51</td><td>26.0</td><td>71.0</td><td>63.0</td><td>1740</td></tr>
</table>
</td></tr>
<tr><td>1970</td><td>Proc.Roy.Soc.
A.319 32-44
(RJE Glenny)</td><td>Fibrous Reinforced Metallic Matrics</td><td>Fibrous reinforced metals and alloys were examined against a possible use in turbines at about 800°C continuously.</td></tr>
</table>

contd...... on sheet 2

Reference

Synopsis

1976 RPE L.Div. Paper LDP 47/76 (F. E. Nicoll)

Combustion Chamber linings for a packaged liquid propellant test engine.

Describes an examination of chamber linings moulded at Banwell from glass fibres or silica fibres or a combination of them with a phenolic resin. It was concluded that the 50:50 glass fibre/resin mix was promising for this application. The materials examined were:-

118 Glass fibre choppings	F7S Refrasil choppings	Phenolic resin			Xylok 210
		J.1011H	J.1004H	J.2200S	
50		50			
	60	40			
	60		40		
	60			40	
	60				40
30	30	40			

Undated SRS Report (M. J. Chase)

Insulation for solid propellant rocket motors. Requirements, current practice and future trends.

This report is believed to have been prepared for presentation to a working party; it is a review report. Distinction was made as to whether the insulation is in physical contact or not with the propellant because in areas of the first type there was a need for the strength, expansion and bonding properties of the insulation to be similar to the propellant as well as a requirement for chemical compatibility. Insulation of other areas is usually prone to severe erosion so reinforced plastics are preferred to the elastomeric materials needed in the first category application. Graphite is also satisfactory alternative to reinforced plastics especially for short burn time motors.

In the instance of elastomeric insulation the activation energy of the polymer used has shown some correlation with the performance of the insulation and the following figures were quoted:-

Experimental activation energy of decomposition Kcals/mole						
100	80	61-66	55-60	45	31-35	26-30
Fluorocarbon	E.P.T.	Polyetherurethane Butyl Hypalon	Silicone EP copolymer SBR	Neoprene	Nitrile Polyisoprene	Natural Polyurethane

Useful insulation by elastomeric polymers is only obtained by use of suitable fillers and three possible types that can be used, usually in combination, were cited; thus:-

Decomposing Below degradiation temperature	Decomposing Above degradation temperature	Non Decomposing
Boric acid Potassium oxalate Antimony trioxide	Calcium hydroxide Magnesium hydroxide Lead chloride	Finely divided silica

Reinforced plastic insulation usually involves a high fibre content and a paradox exists because although they may be orientated either for maximum resistance to erosion or for maximum strength an orientation normal to the gas flow, to reduce erosion to a minimum, then results in thermal conductivity through the insulation wall being at its maximum rate.

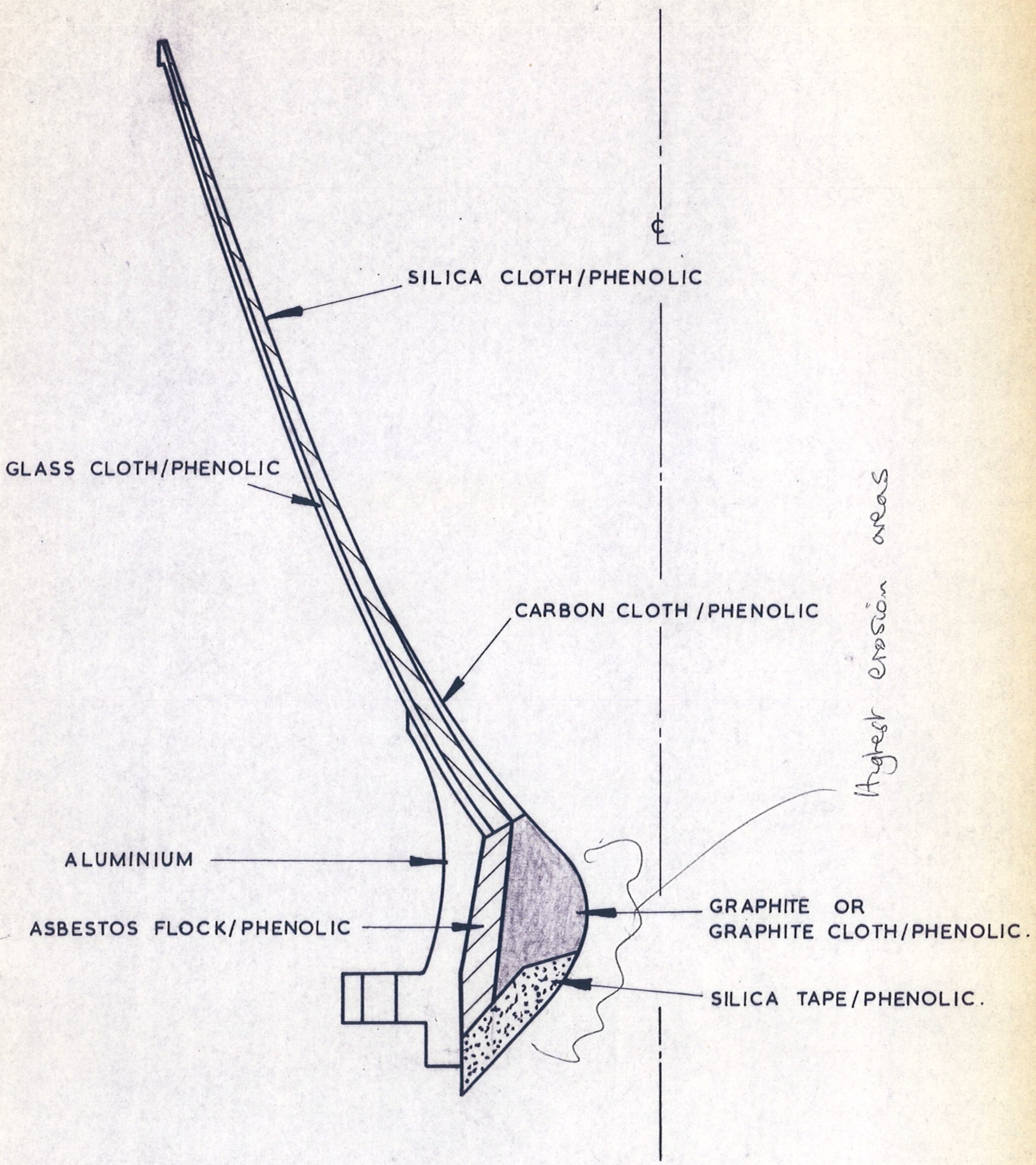
Asbestos is probably the most widely used fibre because of its low cost, low conductivity and its ability to absorb energy by loss of closely bonded water molecules at about 700°C but silica, low modulus carbon and graphite fibres are used at the expense of strength and conductivity whenever a higher resistance to erosion is essential. The following figures from static motor firing tests illustrated these characteristics:-

	Asbestos	Silica	Graphite
Attack rate µm s^{-1}	140	203	290
Erosion rate µm s^{-1}	51	-33 (swollen)	nil

Phenolic resins are the more widely used matrices in these reinforced plastics, because of their aromatic structure and composites made with them have strain values of 0.2-0.4% at break unless modified by additions of elastomeric or thermoplastic polymers. Fabrication methods mainly involve the use of matched metal mould tools in compression, transfer or displacement techniques and high length to diameter ratio components can be produced separately or directly moulded into structural components or around throat inserts. The review gave a short account of practice in the USA in which it is pointed out that the large components being produced there have to be fabricated by string and/or tape winding or hand lay-up methods because matched die tools not only become gigantic in size and cost but few presses exist in the world which are large enough and sufficiently robust, to handle them. The attached figure was used to show how composite/composite techniques are used in rocket motor design.

END OF APPENDIX 4

APPENDIX 4
FIG. 1



TYPICAL ROCKET MOTOR NOZZLE SHOWING USE OF COMPOSITE – COMPOSITE ASSEMBLIES.

SPECIFIC EXAMPLES OF THIS TYPE OF ASSEMBLY ARE GIVEN IN APPENDIX 2 OF THIS REPORT.

SA 10101

APPENDIX 5

RESTRICTED - U.K. EYES (B)

NOZZLES	Flame temperature up to 2750 K and burning times up to 15 s. When flame temperatures may be up to 3300 K.	Bristol Aerospace Winnipeg use either Speer 890S or Union Carbide ATJ graphites for lining the steel structure in the throat area. The steel expansion cone is coated internally with sprayed alumina applied by the Rockide process. The graphite lining has a secondary insulation formed by a silica/phenolic moulding produced from diced squares of fabric prepreg. Unsupported silica/phenolic composite has been used successfully as the expansion cone at these temperatures for nozzles with dimensions of about 430 mm length and 300 mm diameter. At Defence Research Establishment Valcartier (DREV) the standard nozzle for their CRV 7 motor has a nozzle moulded from chopped glass/phenolic (Fiberite 16771) but with a Speer 890S graphite throat insert. The motor has a typical firing time of 2.5 s and uses a highly aluminised propellant; its length is 34 inches and it has a 4 inch diameter. DREV have been considering the replacement of this nozzle by an asbestos phenolic flock such as Durez 23639 and have also examined a wet graded asbestos moulding material produced by Bristol Aerojet Ltd.
CASE LININGS	In 1962 DREV report CARDE TM 676/2 gave a description of their universal spinning machine for applying even layers of restrictor to the inner parallel portions of rocket engines. An overall 0.060 to 0.080 thickness was applied in this way to Black Brant III with an additional thickness of 0.020 inch applied over a three foot length at its nozzle end (this restrictor is an insulating layer of inert material to which the propellant will bond chemically). The restrictor was a polyurethane containing 31.3% of mica powder and based on a polypropylene glycol modified with di-2 ethyl hexyl azelate and crosslinked with 2-4-6 tolylene diisocyanate (this material is known as CARDE flex and has a similar composition base to CARDE A24RX5 propellant). 4 inch diameter motor cases 6 ft. in length had been coated with a 0.100 inch thickness of this type of lining to have a tolerance of ± 0.002 inch using rotational speeds of 600-700 rpm. This type of material and technique has since been used by Bristol Aerospace in their 15KS 25000 motor which has a flame temperature of 2750 K; their technique involves an initial spreading at 50 - 75 rpm followed by hand brushing at a slower speed to give a more uniform film, and then curing for about 30 min. whilst blowing hot air into the rotating case.	

END

APPENDIX 6

	Date	Title	Reference	Synopsis
1.	1958	Phenolic/fibre combinations	Gruntfest and Schocker SPI Conference February 1958	Fibres examined were Nylon, glass and asbestos and ranked in that order when assessed using flux densities of 430 BTUs/sec/ft^2 for 60 seconds exposure. The high resistance of Nylon to erosion was attributed to the high rate of evolution of hydrogen at 6000/12,000^{0}F.
2.	1959	Evaluation of plastics for rocket motor nozzles.	G.Epstein and H.A.King Paper SP.TP.16 Am Chem Soc Symposium September 1959	Assessments made by liquid fuelled test motor (SPAR) at Aerojet General concluded at 5400^{0}F test condition high melting point, refractory reinforcements perfomed better than organic or other low melting temperature fibres. Thin refractory coatings were not found to be beneficial. Spar ratings of materials were:-

Highest Resistance 5	3	2	<2	1	<1
Silica/phenolic Silica/phenolic-silicone	Rockhide Cr_2 Ni B_4 Fibrefrax/epoxy Fibrefrax/melamine	Rockhide Al_2O_3 Metco Al_2O_3 E-glass/epoxy Glass/copper	Molybdenum on aluminium (Metco)	Stainless steel mesh Asbestos mat RM.9517	Zirconia powder Magnesium oxide powder Magnesium oxide/glass fibre Phenolic micro balloons

	Date	Title	Reference	Synopsis
3.	1960	Behaviour of plastics in re-entry environments	D. L. Simmonds Mod. Plastics March 1970.	Arc plasma jet evaluations by 10 second exposure.

Resin	Fibre Amount / Type	% Thermal Efficiency BTU/lb				% pbw	Weight loss lb x 10^{-3}			
		40	55	70	75		40	55	70	75
Phenolic	Silica	7000	7800	7900			5.84	5.29	5.18	
	Nylon	7200	7600		6400		5.66	5.38		6.37
	Glass	6000	5800	4900			6.90	7.01	8.37	
	Asbestos	5600	5900				7.27	7.45		
Melamine	Silica		6900		7900			5.91		5.18
	Glass	3800	3900	4600			10.89	10.54	8.84	
Silicone	Silica	All delaminated					All delaminated			
	Glass			6000					6.79	

Order for rate of substrate temperature rise was(in decending order.)

Graphite, graphite/phenolic, glass/phenolic, asbestos/phenolic, silica/phenolic. All the reinforced plastics took 5 to 6 times longer than the graphite to reach the same back face temperature.

contd...... on sheet 2

Contd...... from sheet 1

	Date	Title	Reference	Synopsis
4.	1961	Nozzle system for hybrid propulsion system	A. J. Robinson, A. L. McAlexander G. J. Wydro NAVWEPS Report 7802	Requirement was for aluminised propellant with IRFNA injected during firing. The actual flame temperature was 3427°C (6200°F) and pressure of 1000 psi for >30 seconds and with condensable solids of >25% by weight. Materials examined were:- W/Cu, W/Al_2O_3, W/BeO, $85W/15\ Mo$, $W/Zr\ O_2$ Graphite cloth, Graphite Stainless steel film ZrO_2/phenolic 90 Ta/10 W 90 Ta/10 W + graphite cloth XP.202 cloth Thin walled Mo or Ta Concluded W impregnated with Cu gave best performance in plasma arc heat source but programme was said to be being extended to include pressure driven liquid metal cooling through W and graphite matrices.
5.	1962	Ablative elastomeric insulation materials	R. E. Headrik Wright Patterson Air Force Base Report ASD-TDR-62-400	Sought alternatives to the 5 to 10% elongation/elastomeric insulations in wide use at the time; these materials were:- NBR 100 pbw Phenolic resin 40 to 120 Filler 100 to 200 Assessment was by an early possible ASTM torch test using a 2 x 2 x $\frac{1}{4}$ inch specimen and 45° flame impingement but was not adopted in the final specification test. Plasma torch test was also used. The NBR compounds were only rated fair by these tests when compared with silicone, polysulphide and vinyl pyridine acrylonitrile compounds all of which gave better thermal protection. The polymers examined, in alphabetical order, were:- Adiprene Brominated butyl, Hycar 2202 Butyl RC Enjay 325/SP 2055 Enjay 325/Altax. TMTDS. Sulphur C S 4 polybutadiene Chloro butyl cyanosilane MD 551 Ethylene propylene ERR.40 Ethyl acrylate Hycar 4021 FBA (IF4) Fluorosilicone L 563 Genthane S Hypalon 40 Kel F 5500 Natural NBR Paracril D Paracril 18-80 Neoprene WRT Polyisoprene SBR Stypol 1000 Silicone RTV Union Carbide K.1046R Thickol ST FA Vinyl-Pyridine Viton B

contd.......on Sheet 3

contd...... from sheet 2

	Date	Title	Reference
6.	1962	The performance of selected plastics materials in a high temperature environment	A. Fisher et al Naval Ordnance Laboratory Report NAVWEPS No.7390

Synopsis

Basis of comparison was Index of Performance by ASTM torch test (1962 version). Various fillers were added to NBR/phenolic resin compound in amounts of nil, 20, 40, 60 and 100 per 100 parts by weight of the resin constituent. Increasing the concentration of the low melting point fillers decreased the amount of phenolic available and resulted in a reduction of the amount of temperature resistant char the coolant gases produced. The introduction of super refractories e.g. ZrO_2 enhanced the resistance to erosion but no instance was found of any particular inorganic refractory fibre enhancing the resistance to erosion as well as giving an improved IP value.

If phenolic micro balloons were used to increase the pore structure by predetermined amounts, the effect was to stabilise the IP but to cause an increase in erosion loss initially possibly due to dislocation of the normal pore structure of the unfilled NBR/phenolic initially, until a more homogenous pore system had been built up by increased additions of micro balloons.

Varying rates of PBA to phenolic resin were examined as unfilled compounds. W96 silicone and Neoprene WRT were also substituted for this matrix when considering ZrO_2 as the filler.
Relevant data given in this report is:-

UNFILLED COMPOUNDS

PBA Hycar 1042	pbw	100	50	25	10	5	Nil
Phenolic Durez 12687	pbw	Nil	50	75	90	95	100
Time to reach 300°C		10.0	39.1	35.0	44.0	40.4	39.6
Erosion rate mils/sec		25.3	4.3	4.2	3.3	4.6	4.4
Index of Performance		505	22	24	15	23	22

PHENOLIC MICRO BALLOONS

100 pbw PBA/90 Durez 12687	100	100	100	100	100
Phenolic Micro Balloons pbw	Nil	20	40	60	100
% of mix	0	16.7	28.6	37.5	50
Time to reach 200°C secs.	51.0	59.5	43.6	50.6	46.7
Erosion rate mils/sec.	3.3	4.4	4.4	4.0	3.9
Index of Performance	13	15	20	16	17

DIFFERENT POLYMERS

Matrix	ZrO_2 Addition	Time to reach 200°C (s)	Erosion rate mils/s	Index of Performance
100 PBA:90 Durez 12687	Nil	51.0	3.3	13
Neoprene WRT		8.0	22.4	560
Neoprene WRT	280	13.0	42.0	646
Silicone W96		11.5	25.0	435
2 pt phenolic Durez 10694	400	30.9	4.2	27

contd.......on sheet 4

contd.......from Sheet 6

	Date	Title	Reference	Synopsis
27.	1968	Structural design and thermal properties of polymers.	G.F. d'Alelio ACS Div.Organic Coatings, Plastics, Chemistry 28 - 1 19 (1968)	Author distinguished between subliming and charring ablators thus:-
28.		Review of ablative studies of interest to naval applications	F.J. Koubeck, ACS Div.Organic Coatings Plastics Chemistry 28 - 1 8-14(1968)	ASTM Ablative Torch Test Results; ALPHA ROD Test Results

27. Author distinguished between subliming and charring ablators thus:-

SUBLIMING	Have porous refractory continuous phase matrix filled with a material which gasifies at a high temperature and thus delays a rise in the surface temperature of the matrix long enough to prevent it melting during the mission.	Typical examples are polymers which depolymerise quantitatively and reversably such as poly-ethylene, polystyrene, PTFE, some nylons and several poly-urethanes.
CHARRING	Generate a large amount of char residue under hyperthermal conditions to act as the binder for reinforcement(s) embedded in it.	Generally the higher the thermal stability of the polymer the greater the yield of char. Fillers include nylon, asbestos, glass, silica graphite.

28. ASTM Ablative Torch Test Results

Erosion loss mils/sec.	Filler	Phenolic resin	PBA/phenolic	Silicone	PBA	PBS
1.2	Graphite Cloth	●				
2.8	Gran Graphite	●				
	Al Silicate	●				
3.2	Pot Oxalate		●			
3.4	Asbestos Mat	●				
	Silicate cloth	●				
3.6	Asbestos fibre	●				
	Asbestos fibre					●
4.4	Asbestos fibre			●		
4.6	Ceramic fibre	●				
5.7	Quartz fibre	●				
6.4	Asbestos fibre				●	
11.6	Silica powder				●	
13.9	Cork			●		
14.1	Cork				●	
14.3	Silica powder		●			
15.6	Nylon Cloth	●				

ALPHA ROD Test Results

Ablation rate cm/s x 10^{-3}	Filler	Phenolic	PBA/phenolic	Silicone	PBA	Heat of ablation cal/g
1.80	Silica fabric	●				12700
3.05	Pot Oxalate		●			9015
3.52	Asbestos fibre	●				7950
3.77	Asbestos mat	●				8400
4.31	Boric acid		●			6640
6.66	Asbestos fibre				●	5860
13.8	Pressed cork	●				5970
15.0	Cork			●		4120
19.8	Nylon	●				3420

The following data was also given:

Density

ASTM Torch Insulation indices
Time to 200°C back face temperature

ALPHA RED Char diffusitivity 400°C.

contd......on Sheet 8.

contd....... from sheet 7

<table>
<tr><th></th><th>Date</th><th>Title</th><th>Reference</th><th>Synopsis</th></tr>
<tr><td>29.</td><td>1969</td><td>Structural synthesis of composite materials for ablative nozzle extensions.</td><td>E.R. Scheyhing and G.D. Summers
(origin not quoted)</td><td>Primary structural element of nozzle (skirt) of Stage II of Tritan III is a glass/phenolic honeycomb sandwich protected by an asbestos/phenolic prepreg tape wound at an initial 45° to the mandrel.
The exterior of this skirt has to be protected by silica batt because it is exposed to the plume from the roll control nozzle.
Details about construction and materials used are given.</td></tr>
<tr><td>30.</td><td></td><td>Opacified fibrous insulation.</td><td>W.E. Grunert et al
AIAA 4th Thermophysics Conference.
San Francisco.</td><td>Protection against rediant heat obtainable by partially replacing some of the fibre in a multi layer fibrous insulation, thus:-
<table>
<tr><th>Fibre replaced</th><th>Present</th><th>Replaced by</th><th>Recommended max. service temp. °F</th></tr>
<tr><td>Glass</td><td>Al foil</td><td>Al flakes</td><td>900</td></tr>
<tr><td>Quartz</td><td>Cu foil</td><td>Cu flakes</td><td>1400</td></tr>
<tr><td></td><td>Ni foil</td><td>Ni flakes</td><td>1700</td></tr>
</table></td></tr>
<tr><td>31.</td><td></td><td>Study of characteristics of refractory materials under high velocity flight conditions.</td><td>AFML Report TR.69-54</td><td>Materials containing solid oxides showed lower erosion in hot gas/cold wall conditions than in a cold gas/hot wall exposure for the temperature conditions used.
The following materials were examined:-
Silica plus 35%, 60% or 68% vol: vol of tungsten
Zr or Si graphites
A range of coated metals
Hf B, with or without 14% SiC
HfB plus 20% or 35% SiC
ZrB alone or with 5% carbon</td></tr>
<tr><td>32.</td><td>1970</td><td>Boride composites. A new generation of nose cap and leading edge materials for re-usable lifting re-entry systems.</td><td>L. Kauffman
AIAA Mtg.Feb.1960, Florida on Advanced Space Transportation.</td><td>Materials for use as composites for long exposures in oxidising environments at 2500-5000°F; they include:
Hf B Hf $B_{2.1}$ Hf $B_{2.1}$ + 20% or 35% SiC vol: vol.
Zr $B_{2.1}$ + 20% SiC vol: vol
Zr B_2 + 14% SiC + 30% C vol: vol
Evaluation was by hot gas/cold wall plasma arc and cold gas/hot wall furnace methods showed the performance of this type of material was unrivalled by any known materials.
Materials are formed into shapes by conventional hot pressing methods, such as those used for producing body armour and helicopter seats but is at present limited to components within a 6 inch to 12 inch range.</td></tr>
<tr><td>33</td><td></td><td>Heat Shield Materials</td><td>Info sheet A-40-70, Def. & Res.Div.
Staff British Embassy, Washington, reporting on USAF Materials Symposium Florida, May 1970</td><td>N. American Rockwell evaluating Haynes 188 proprietary material, zirconia felt, Zr Br_2, silicon coated columbium, thoria dispersed Ni/Cr alloy, for use as insulation protection in advanced projects.</td></tr>
<tr><td>34</td><td></td><td>Moulded glass/phenolic inserts replace graphite in Astrobee D low cost sounding rocket</td><td>Aviation Weekly & Space Technology 3 No. 93
July 1970</td><td>Nozzle of this 6 inch diameter 44 ft long rocket has a moulded glass/phenolic nozzle, which is designed to ablate in flight to give a controlled regulation of chamber pressure.</td></tr>
</table>

contd........on Sheet 9

<table>
<tr><th></th><th>Date</th><th>Title</th><th>Reference</th><th>Synopsis</th></tr>
<tr><td>35.</td><td>1970</td><td>Development of non metallic external insulation thermal protection systems for space shuttles</td><td>P. D. Gorsuch et al
SAE Reprint 700771
Space Technology Forum of NASE, Meeting Los Amgeles October 1970</td><td>Performance of pyrolysed composites was improved by the addition of carbide materials - R.120 graphite fabric was graphitised after addition of Si, Si/Mo, Si/B, Si/SiC. Inhibitors added as well included a ZBr_2 + 14% SiC + 20% C systems and an Hfc + C system.
Article also mentioned development of REI silica and REI mullite coatings by Gen. Electric as well as hybrids of these materials with or without the addition of ZrO_2.</td></tr>
<tr><td>36.</td><td></td><td>Development status of re-usable non metallic thermal protection</td><td>D. Greenshields et al
Paper 1. Symposium NASA Langley.Research Center 1971</td><td>Oxidation resistant carbon-carbon laminates were being considered for space shuttle applications and with the surface of the carbon cloth/polymer being treated with Si or Zr before pyrolysis. The carbide surface formed although much weaker than the substrate had good resistance to oxidation. Composites of this nature examined were:-
<table>
<tr><th>Reinforcement</th><th>Matrix polymer</th><th>Inhibitor</th></tr>
<tr><td>Graphite cloth</td><td>Phenolic</td><td>Si</td></tr>
<tr><td>Carbon cloth</td><td>Epoxide</td><td>ZBr_2/Si</td></tr>
<tr><td>Carbon yarn</td><td>Furfuryl resins</td><td>Ti/Si</td></tr>
<tr><td>Graphite filament</td><td>Pitch</td><td>Ti/Si</td></tr>
<tr><td>Carbon filament</td><td>Chemical vapour deposition of Zr Si or Hf/Si</td><td></td></tr>
</table>
Phenolic and epoxides were said to be the preferred initial binder, with or without an addition of a refractory oxide.
Chemical vapour deposition of the inhibitor, after initial pyrolysis, has been used and both pitch and furfuryl alcohol have been used to fill the pores before further pyrolysis.
'Commercially' available materials were:
<table>
<tr><td>Lockheed Missiles & Space Corp.</td><td>L.11500</td><td>Silica fibres bonded with a silicate with a coating of Cr_2O_3; said to be re-usable up to 1530 K</td></tr>
<tr><td>McDonnell Aerospace Corp.</td><td>HCF</td><td>Mullite fibres bonded by a silica, borasilicate glass, phosphate mixture and with a CoO surface for high emittance; said to be re-usable up to 1640 K.</td></tr>
</table></td></tr>
<tr><td>37.</td><td>1971</td><td>Ablative thermal protection systems</td><td>L. F. Voster & C.M.Poblman
Paper 5. Symposium NASA Langley Research Center 1971</td><td>Although long term resistant protections were being developed as alternatives, this paper shows that the feasibility of using cheap and easily replaced ablator panels of low density phenolic-nylon composites and filled silicon elastomers was not being ignored.</td></tr>
<tr><td>38.</td><td>1972</td><td>Evaluation of RSI materials</td><td>C. W. Kittler et al
Batelle Columbus Labs. Report 1972</td><td>Although this report dealt mainly with methods for evaluating non metallic insulating materials, mention was made of three commercial products tested:- (reference to these products not given)
<table>
<tr><td>General Electric</td><td>Hard brittle failure at about 520 K</td></tr>
<tr><td>Lockheed</td><td>Survived 1367 K without failure</td></tr>
<tr><td>McDonnell Douglas</td><td>Softened at about 1089 K</td></tr>
</table></td></tr>
</table>

contd.......from Sheet 10

contd.......from Sheet 9

	Date	Title	Reference	Synopsis
39.	.	Advanced solid propellant motor insulation	P. L. Smith and R. F. Russ Aerojet Solid Propulsion Co. Sacramento Report CR-11413 July 1972	Basic objective was to provide an improved light weight insulation for a low thrust long duration Aerojet General space propulsion motor. The target was a two fold improvement on the Gen Gard 4030 EPDM used at the time, screening by the Laboratory Insulation Test Evaluation (LITE) solid propellant motor.

Binders examined included

EPR, NBR as premouldings	CTPB, HTPB, PBAN as mastics	Phenolics as hard plastics

and the fillers examined included

Aluminium silicate
Ammonium benzoate
Ammonium sulphate
Antimony oxide
Asbestos
Hexa methylene triamine
Kaowool
Micarta (paper reinforced phenolic) crushed and ground
Microballoons (borosilicate glass and FDT 202 high strength silica)
Phenolic powder
Refrasil

Two promising materials both based on PBAN, reference IBT 122 and IBT 124 were evaluated as insulation for a SVM2 chamber.

The overall conclusion was that a dual layer of IBT 123 inner with an IBT 124 outer layer was at least 1.6 times better than Gen Gard 4030.

The use of ammonium benzoate, ammonium sulphate or hexa methylene triamine or coolants by their thermal degradation to ammonia and then to hydrogen was of particular interest.

40.	1973	MC M^1O_2 Composites. A new thermal insulator	R.E. Riley and J.M. Taub Los Alamos Labs.Univ. California, Report LA 5136 Feb.1973	Development of refractory metal carbide - metal oxide composites for use in high temperature insulation within the Rover nuclear reactor where it has to withstand 2000°C in a hydrogen atmosphere. It is believed these materials operate by forming oxycarbides of general formula $MM^1C_xO_y$ where M, Ml can be Ti, Zr Hf, V, Ni, Ta, Th and U.

Composites examined listed were:

ZrO_2	ZrC	NbC
75	25	with & without Co. stabilisation
50	50	
25	75	
25		75
50		50
75		25

UO_2	ZrC	HfC	HfO_2
75	25		
50	50		
75		25	
50		50	
		25	75
		50	50

41.		Refractory chamber materials for N_2O_4/amine propellants	J.G. Campbell AFRPL Report TR-73-31	Evaluation of passively coated nozzles by test firings at 400/600 lbf in^{-2}. Edgewise orientated washers of zirconium pyrocarbide and Hafmium pyrocarbide eroded badly if compared to pyrolytic graphite. Pyrolytic graphite coated Carbitex (Carborundum Co.) gave low erosion rate of about 6 mils/sec. The lowest erosion rate was obtained with zirconium dibromide (Man Labs) made in two segements to resist the shock of thermal expansion at firing.

Melting points quoted were:-

4620°C	Be O
4690	Ca O
4860	Zr O_2
4980	Ce O
5070	Mg O
5282	HfO_2
5970	ThO_2

contd......on Sheet 11

contd.......from Sheet 10

	Date	Title	Reference	Synopsis
42.	1973	Reliability and effective thermal conductivity of three metallic-ceramic composite insulating coatings on cooled hydrogen-oxygen rockets	H.G. Price Jr. et al NASA T.N. 07392	Grade coatings on the inside of a LOX motor thrust chamber were examined by static motor firing tested. (Grading was employed to overcome the sharp transition introduced in a single coating and coatings were applied by plasma spray).

Layer 1	Layers 2,3 and 4	Layer 5	Survived *
Mo	3 off Mo/ZrO_2 of varying composition	HfO_2/ZrO_2	17 cycles for a total of 213 s.
Mo	3 off Nichrome/M_2O_3	Al_2O_3	6 cycles for a total of 182 s.
Mo	2 layers only Nichrome/Al_2O_3	-	6 cycles

* All coatings were thought to be capable of further cycling.

	Date	Title	Reference	Synopsis
43.	1974	Performance of materials in a ramjet environment	L.S. Cohen et al AIAA/ASMF Conference Boston July, 1974	A gaseous propane/air flame was used to test blast tubes 3.82 in. diameter and 16 inch length against mission requirements of at least 200 s. at 2300^0 or 3700^{0}F. Candidates were to be used to replace the 60/85 mils thick zirconia liner in an air launched low volume ramjet. Materials examined were:-

parts by weight

Ref.		Resin and catalyst	Silica			SiC	Asbestos fibre	Carbon fibre	ZrO_2
			Powder	Microsphere	Fibre				
DC93.104		46	50+SiC					4	
GE 655		65	20	6				4	
JM 700		40					60		
Fiberite FM.2222		40			60				
United A/C Labs	DC	40			50			4	
Formulae		71		17			12		
		70	20	6				4	
	GE	42							
		75	11	10				4	54
	JM	69		19			12		

DC 93.104 was found to be the more promising ablative material for all 3 of the ALVRJ missions and although considerable erosion occurred, swelling of the char resulted in little change in throat area.

GE 655 was inferior and would have to be used as a much thicker layer than DC 93.104 but did not swell or fissure in the throat area. Fiberite 2222 could be attractive if the flame was hot enough to cause melting.

contd......on Sheet 12

contd.......from Sheet 11

<table>
<tr><th></th><th>Date</th><th>Title</th><th>Reference</th><th>Synopsis</th></tr>
<tr><td>44.</td><td>1974</td><td>High chamber pressure blast tube and nozzle material evaluation Vol.1</td><td>W.A. Stephen et al
United Technology Corp.
Report 2410-FR</td><td>A summary of results obtained between 1971 and 1974 when evaluating effect of propellant chemistry, solids loading and blast tube configuration upon nozzle materials in high chamber pressure motors within the 2500/3500 lb in^{-2} range, using the UTC Hippo motor.

Materials tested were:-

<table>
<tr><td>As blast pipes</td><td>Carbon, polycrystalline graphite, carbon/carbon composites, silica, hybrids of carbon and silica, phenolics</td></tr>
<tr><td>As aft closures</td><td>Glass phenolic or elastomers</td></tr>
</table>

All three carbon/carbon composites tested failed by ejection of the liner.

Recommendations made were:-

<table>
<tr><td>Aft closure</td><td>Durez 16771 glass phenolic or R.155 EPDM/asbestos</td></tr>
<tr><td>Fwd.entrance cap</td><td>Flat laminate of MX.4926 (carbon/phenolic)</td></tr>
<tr><td>Aft entrance cap</td><td>Graphitex G.90</td></tr>
<tr><td>Throat insert</td><td>Techmet wire wound tungsten</td></tr>
<tr><td>Exit cone</td><td>MX.4926 or
FM.5055</td></tr>
</table>
</td></tr>
<tr><td>45.</td><td></td><td>Castable thermal insulation for use as heat shields</td><td>A.J. Mountvalar et al
Ceramic Bull. <u>53</u> No.11
1974</td><td>Formulations of low density ceramic foams using Zircon (Zr O_2.SiO_2) as the major constituent bound by either aqueous potassium silicate or mono aluminium dihydrogen phosphate, and foamed with egg albumin are given. In some instances refractory fibres such as Fibrefrax or fillers such as alumina were added.</td></tr>
<tr><td>46.</td><td>1975</td><td>Development programme to produce Mullite fibre insulation</td><td>W.G. Long,
NASA report CR.134803</td><td>5 Hybrid blankets of Mullite and Kaowool were made by wet laying processes from stable fibres.

<table>
<tr><td>Kaowool</td><td>100</td><td>90</td><td>70</td><td>55</td><td>25</td><td>10</td></tr>
<tr><td>Mullite</td><td>-</td><td>10</td><td>30</td><td>45</td><td>75</td><td>90</td></tr>
</table>

Additions of Mullite > 10% improved the dimensional stability and the refractiveness of these blankets at either 1250^{0} or 1371^{0}C.

Analysis of fibres given was

<table>
<tr><th></th><th>Al_2O_3</th><th>SiO_2</th><th>B_2O_3</th><th>P_2O_5</th><th>FeO</th><th>TiO_2</th></tr>
<tr><td>Mullite</td><td>77</td><td>17</td><td>4.5</td><td>1.5</td><td></td><td></td></tr>
<tr><td>Kaowool</td><td>45</td><td>52</td><td></td><td></td><td>1.3</td><td>1.7</td></tr>
</table>
</td></tr>
<tr><td>47.</td><td></td><td>Furnace Insulation</td><td>J. M. Beilacque
Jl. Canadian Ceramic Soc.<u>44</u>
69-71</td><td>Two new ceramic fibres have been produced for insulating furnaces:-
50:50 alumina/silica for continuous service up to 2300^{0}F
62:38 alumina/silica for continuous service up to 2600^{0}C</td></tr>
</table>

RESTRICTED - U.K. EYES (B)

contd.....on Sheet 13

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<table>
<tr><th></th><th>Date</th><th>Title</th><th>Reference</th><th>Synopsis</th></tr>
<tr><td>7.</td><td>1962</td><td>Metal-phenoxyaldehyde polymers</td><td>A. J. Landry, et al
NAVORD Report No.6390</td><td>Examined metal phenoxy-aldehyde high polymers and in particular Mg^2-Ni phenoxys as possible heat resisting insulation for rocket motor components.</td></tr>
<tr><td>8.</td><td></td><td>Refractory additives to rubber formulations</td><td>US Rubber Co. report to Bur Naval Weapons October 1962.</td><td>Effect of replacing the potassium oxalate filler in a nitrile/phenolic resin compound was examined. This low temperature decomposing filler was replaced by selected refractories limiting the addition made so that the elongation at break of the cured compound was not less than 5% to accommodate the 3% elongation needed to meet the increase in motor case diameter that occurs in firing.
Only fillers were examined because it was considered that the polymer should commence decomposing endothermically about 204°C (400°F) to ensure that the interface between the case and the insulation does not reach elevated temperature until all the insulation thickness has pyrolysed.
Materials examined in preferred order were:-
Zirconia, graphite, Periclase (Magnesia) Flint, Silicon Carbide, Silicon Nitride, Titanium Sulphide.</td></tr>
<tr><td>9.</td><td>1963</td><td>Laboratory techniques for studying thermally ablative plastics.</td><td>H. S. Schwartz
Aerospace 59 No.40 64-80</td><td>Author distinguished between three categories of materials, thus:-
<table>
<tr><td>Unreinforced.</td><td>Cat.1</td><td>Materials which decompose into gases when heated to leave almost no char.</td><td>e.g. PTFE, polyethylane, polyamides & acrylics.</td></tr>
<tr><td></td><td>Cat.2</td><td>Decompose to produce chars as well as gases.</td><td>e.g. phenolics, phenyl silanes, furanes, special epoxide formulations and some elastomers.</td></tr>
<tr><td>Reinforced.</td><td>Cat.3</td><td>Category 2 plastics containing re-inforcements of nylon, cotton, glass, asbestos or silica fibres or combinations of them.</td><td></td></tr>
</table>
Paper gave following data for a 62% glass fibre 38% phenolic composite.
<table>
<tr><th colspan="2">Region</th><th>C</th><th>H</th><th>O</th><th>N</th><th>Residue</th><th>Ratio by weight Carbon/residue</th></tr>
<tr><td colspan="2">Undegraded</td><td>28.75</td><td>2.15</td><td>7.66</td><td>0.34</td><td>61.60</td><td>0.46</td></tr>
<tr><td colspan="2">Volatile loss regions</td><td>27.77</td><td>1.93</td><td>6.87</td><td>0.13</td><td>63.30</td><td>0.44</td></tr>
<tr><td colspan="2"></td><td>27.04</td><td>1.59</td><td>5.75</td><td>0.17</td><td>65.45</td><td>0.41</td></tr>
<tr><td>Char</td><td>Inner</td><td>23.32</td><td>0.39</td><td>1.40</td><td>0.12</td><td>74.77</td><td>0.31</td></tr>
<tr><td></td><td>Middle</td><td>26.96</td><td>0.16</td><td>0.93</td><td>0.10</td><td>71.85</td><td>0.38</td></tr>
<tr><td></td><td>Outer</td><td>30.00</td><td>0.09</td><td>-</td><td>0.20</td><td>66.64</td><td>0.50</td></tr>
</table></td></tr>
<tr><td>10.</td><td></td><td>Silica/phenolic moulding materials</td><td>McDonnell Aircraft Report No. A.751</td><td>Reported following tensile strength of mouldings produced under various moulding pressures from ½ x ½ inch square chopped fibre from Refrasil MX.2625 prepreg. fabrics.
<table>
<tr><th rowspan="2">Moulding pressure lbf in^{-2}</th><th colspan="3">Tensile strength as % of room temperature strength obtained for a moulding made at 1500 lbf in^{-2}, when tested at</th></tr>
<tr><th>Room</th><th>500°F</th><th>700°F</th></tr>
<tr><td>250</td><td>52</td><td>20</td><td>17</td></tr>
<tr><td>500</td><td>54</td><td>23</td><td>18</td></tr>
<tr><td>750</td><td>82</td><td>29</td><td>25</td></tr>
<tr><td>1050</td><td>99</td><td>34</td><td>27</td></tr>
<tr><td>1500</td><td>100
(value not given)</td><td>34</td><td>25</td></tr>
</table></td></tr>
<tr><td>11.</td><td></td><td>Thermal protection of rocket motor structures</td><td>E. P. Bartlett
Aerospace Eng.
Jan.1963 86-89</td><td>Reviews relative merits of methods for producing combustion chambers and nozzles for liquid fuelled rocket motors and claimed that conclusions were applicable to solid fuelled motors as well. Concluded most promising lightweight designs would use linings of high density, polycrystalline or pyrolytic graphites but the use of tungsten or tantalum carbide as throat inserts should be considered also because of the increased resistance to erosion.</td></tr>
</table>

contd......on Sheet 5.

contd......from sheet 4

<table>
<tr><th>Date</th><th>Title</th><th>Reference</th><th>Synopsis</th></tr>
<tr><td>12. 1963</td><td>Programme to examine ablaters</td><td>D. Caum et al
NOL-TR-63-100</td><td>A proposal programme of alpha rod and high pressure plasma arc tests; it listed the systems that were in use at the time and which were to be used as standards; they were:-
asbestos filled phenolics
glass reinforced epoxides
nitrile & silicone rubbers containing asbestos & inorganic salts</td></tr>
<tr><td>13. 1965</td><td>Fabrication characteristics of ablative plastics prepreg. tape for construction of large rocket nozzles</td><td>W. E. Winter
Paper 8th National SAMPE Symposium Aerospace/ Hydrospace.</td><td>260 inch diameter nozzle of Air Force 623A large booster rocket led to a need to develop tape wrapping methods beyond their use for existing medium to large conical components which used silica, carbon or graphite fibres (and tapes) impregnated with phenolic resin.</td></tr>
<tr><td>14</td><td>Carbon and graphite ablative reinforcements</td><td>R. B. Millington
Paper 8th National SAMPE Symposium Aerospace/ Hydrospace.</td><td>Regraphitisation of carbon/phenolic structures produced from rayon precursors was described; it involved the following cycling in an Argon atmosphere:-
Place in furnace at 200^{0}F
Heat to 1500^{0}F at 50^{0}F/5 min.rate
Hold at 1500^{0}F for 30 mins.
Cool to 200^{0}F before removing.
Material had been assessed for the following projects as -
Sections in the nozzle of Polaris A3 exit cones
Cone linings of UTC
Throat approach of Spar mod.II test motor
Throat and exit sections of solid propellant motors
Thrust chamber linings in Rocketdyne fluorine test firing</td></tr>
<tr><td>15.</td><td>Thermal protection of Minuteman</td><td>L.M. Harold & E.S.D. Diamont
Paper 2nd AIAA Aerospace Conference 1965</td><td>Minuteman has an external insulation of sheet cork to protect its structure during launch. This sheet is AC 2755 (Armstrong Cork Co.) and is finely ground cork in a phenolic resin matrix. Main research activity was the development of a mathematical model from which thermal performance of cork under launch conditions might be predicted, so the behaviour of cork over a wide range of thicknesses and heating intensities was examined.</td></tr>
<tr><td>16.</td><td>Optimisation of reinforced plastics in ablative rocket motor nozzle and re-entry body applications.</td><td>W.C. Jones & D.C. Siverts
Paper 8th National SAMPE Symposium Aerospace/ Hydrospace.</td><td>Techniques being considered for nozzles of Titan III, Surveyor and 156 inch large booster motors were compression moulding rosette lay-ups as alternative to tape wrapping from straight or bias cut tapes. Features of this, then, novel method were described.</td></tr>
<tr><td>17.</td><td>Performance assurance for orientated fibre ablative components.</td><td>R.M. Buck
Paper 8th National SAMPE Symposium Aerospace/ Hydrospace.</td><td>Main feature of paper was publication of Fiberite's 'Snapcure' prepregs which cured at a temperature only slightly above their softening (tacking) temperature.
Materials available included woven fabrics, mats, papers or felts produced as prepregs and containing fibres such as inorganic oxide (e.g. Zirconia), glass, silica, asbestos, carbon or graphite and synthetics (e.g. Nylon).</td></tr>
<tr><td>18.</td><td>Recent advances in high temperature resin binders-A survey.</td><td>J.T. Trainer
Paper 8th National SAMPE Symposium Aerospace/ Hydrospace.</td><td>Author cited three main groups for use in three expected exposures - they included :-
<table>
<tr><th>Type 1 204 - 232^{0}C</th><th>Type 2 316 - 371^{0}C</th><th>Type 3 427 - 482^{0}C</th></tr>
<tr><td>Phenolics
Phenyl silanes
Dow QX 2682 Diphenyl oxide
High temperature epoxides</td><td>Polybenzamidazoles
Du Pont PI 3301 polymide
Polybenzoxazoles
Polyphenylene sulphide</td><td>Some boron hydride based polymers
Olin Mathieson Pop I
Pop II
Pop III
All still in development states</td></tr>
</table></td></tr>
</table>

contd........on Sheet 6

contd.......from Sheet 5

BAJ-TR.347-1978

Date	Title	Reference	Synopsis
19. 1965	The A3 Polaris nose fairing. A structural composite of wood and aluminium	F.B. Johnson & V.P. Manone Paper 8th SAMPE Symposium Aerospace/Hydrospace	Details development and construction techniques used for the 94 inch long by 54 inch diameter base monocoque bullet shaped shell used on this ICBM.
20.	Continuous bias tape wrapping of ablative components.	S. Salzinger Paper 8th SAMPE Symposium Aerospace/Hydrospace	Components needed by 1965 could no longer be produced satisfactorily by compression moulding so tape wrapped hardware was being made for Polaris A3, an advanced design of Minuteman, Titan II, Titan III and the 156 and 260 inch solid booster motor.
21.	Carbon dioxide frost as an insulation for hypersonic spacecraft.	J.P. Clay Paper 8th SAMPE Symposium Aerospace/Hydrospace	A transpirational cooling by the evaporation of solid carbon dioxide supported on a quartz wool batt was proposed for protecting a re-usable hypersonic spacecraft from the effect of aerodynamic heating during its exit from the earth's atmosphere.
22.	Deposition of films from plasma.	F.L. Moritz et al Paper 8th SAMPE Symposium Aerospace/Hydrospace	Thin insulation films of silica can be deposited by plasma arc pyrolysis of ethyl silicate. Metal oxides of either aluminium or tantalum can also be deposited by a glow discharge in the presence of oxygen.
23.	Impregnated foam ceramic insulating materials.	M.A.Schwartz & T.A.Greening Paper 8th SAMPE Symposium Aerospace/Hydrospace	Describes United Technology Centres' techniques. Process is a two stage in which a ceramic skeleton is first produced and is then impregnated with a coolant material such as a phenolic resin. The basic skeleton is formed from fillers and a liquid binder (usually sodium silicate or phosphoric acid) and wetting and foaming agents are added also to the mix. Powders used to form the skeleton have included asbestos, alumina, magnesia, silica, zirconia, titanium and zirconium carbide and zirconium boride, and silica and magnesia fibres and micro balloons have also been used as additional fillers. In general, silicate bonded foams had the best resistance in oxy-acetylene torch tests and a zirconia skeleton impregnated with SC.1008 had withstood plasma arc tests well. Static motor firing tests had included throats and thrust chamber linings which had withstood 60 to 90 sec. duration exposure to flame temperatures of 7000 - 8000°F at 100 - 150 lbf in^{-2}.
24.	Design of ablative thermal protection systems.	J.N. Kotanchick & R.B. Erb Paper 8th SAMPE Symposium Aerospace/Hydrospace	An investigation made into how existing ablative coatings might be improved from those used in the Apollo projects. It was concluded that charring ablators of the filled epoxide type were unlikely to be greatly improved beyond the materials which had already been developed for Apollo and which were improvements from those used in the earlier Mercury spacecraft.
25. 1966	A critique of internal insulation materials for solid propellant rocket motors.	V.F. Hribar J. Spacecraft 3 1434/6 No.9	Effect of adding silica powder and asbestos fibres to NBR (Buna N) SBR (Buna S) and butyl was studied, screening by static motor firing tests in three different sites (5 inch and 29 inch motors at Allegony Ballistics Lab, the TV132 motor at Thickol Corporation and the ETM motor at Aerojet General). The NBR with silica and asbestos gave the better performance as a case lining insulant and the addition of asbestos increased the strength as well as the resistance to ablation. The silica addition increased the melt viscosity and also improved the resistance to erosion. Silica filled SBR had better aging characteristics and had advantage when a shrinkage liner was needed and also had good compatibility with double base propellant with low nitro glycerine uptake. Fibre size and orientation was more critical in SBR than in NBR compounds. New materials reported as being under development at Aerospace Corporation El Segunde were:- NBR - phenolic with inorganic hydrates Butyl with potassium titanate filler Polypropylene/epoxide compounds
26. 1967	Phoenix missile composite thermal insulation system	M.A. Lewis et al Paper 1-2 SAMPE Symposium on Advances in Structural Composites	Materials were selected initially by exposure to high intensity infra red heating and eventually by simulated high speed captive flight conditions in the NASA Langley hot flow tunnel. Materials being considered were:- Cork Sheet (Insulcork 2755), Asbestos paper/phenolic (MX.5700), silica paper/phenolic (MX.5707), two ablative coatings (T.500-4 and X43-44). The cork sheet was found to be the more effective of these materials and could be used on aluminium load bearing structure with an overlay of a Nomex/epoxy laminate (Narmco 570) to protect the cork from damage by abrasion and/or impact, against fungal attack and also to reduce its adsortption of moisture or harmful aircraft fluids.

RESTRICTED - U.K. EYES (B)

contd.......from Sheet 12

<table>
<tr><th></th><th>Date</th><th>Title</th><th>Reference</th><th>Synopsis</th></tr>
<tr><td>48.</td><td>1975</td><td>Role of silica and quartz phenolics in ramjet nozzles</td><td>W. H. Miller et al
ASME Intersociety Conference
San Francisco July 1975</td><td>
<p>Reviews candidate materials for ramjet engines needing insulation in the nozzle entrance, throat and exit cones. Materials considered by Rocketdyne were:-</p>
<table>
<tr><td>Silicone rubber/fibre reinforced</td><td>Insufficient strength contribution-erratic surface ablation</td></tr>
<tr><td>Asbestos/phenolic</td><td>Asbestos melts at about 1482°C</td></tr>
<tr><td>Silica/phenolic</td><td>Silica " " " 3150°C</td></tr>
<tr><td>Quartz/phenolic</td><td>Quartz " " " 3216°C</td></tr>
</table>
<p>Both silica and quartz have high viscosity when molten and would not readily wipe off a throat surface below about 1800/1900°C so Fiberite products MX 1646 (21.4%silica) and MXQ.191 (29% quartz), MIL-A-R-9299 prepregs of 581 Astro quartz (99.04% silica), Siltemp 84 (99.99% silica) were considered further.</p>
<p>Latter two materials were used for moulding as $\frac{1}{2}$ in x $\frac{1}{2}$ in chopped squares which were claimed to give almost perpendicular alignment of the fibre to the gas flow.
MXQ.191 had low resin flow and had to be moulded at 5000 lb in^{-2} compared with 3000 lb in^{-2} needed for MX.2646 but both required a stepped and long cure and post cure under pressure throughout. Resin glaze was removed from the mouldings by grit blast before the post cure and the long cure and post cure were needed to prevent a retention of reaction products which might cause blistering.
16 nozzles were tested on a sub scale ram burner by Martin Marietta at flame temperatures of 2056-2389K for times of between 60-600 secs and pressures of 40-75 lb in^{-2}.</p>
<p>MX.2646 was thought to be the more practical material.</p>
</td></tr>
<tr><td>49.</td><td>1976</td><td>Evaluation of insulating materials for advanced motor systems</td><td>R. T. Robinson
NAVWEPS report NWO TP.5693
May 1976.</td><td>
<p>Study was concerned with nozzle inserts and used two different propellants with the following materials as blast tube linings.</p>
<table>
<tr><td rowspan="2">C518
6 star centred
CTPB + 15% Al
10 s burn
1,500 lb in^{-2}</td><td>0.2 mach</td><td>DC 93.104 (contains 8-10% carbon fibres)
DC 77.151 (50% volume of the silica in DC 93.104 was replaced by 16-20% volume of carbon fibre)</td></tr>
<tr><td>0.4 mach</td><td>DC 93.104
DC 77.151
DC 77.152 (as DC 77.151 but with a 50% by volume replacement of Zirconia for the silica)</td></tr>
<tr><td colspan="2">RS 2
non aluminised
star centred
HTPB 9 s burn
highly corrosive products</td><td>DC 93.104
GE 655 resin and silica to a NAVWEPS formula
R 155 EPT polymer
GE 655 to DC.104 type of formulation
Irish Refrasil (chromic oxide treated silica)</td></tr>
</table>
<p>The following carbon fibre materials were examined as nozzle extensions (venturi) linings</p>
<table>
<tr><th>Matrix</th><th>Reinforcement</th><th>Precursor</th></tr>
<tr><td rowspan="3">EC 201
Resin</td><td>Random CFA$\frac{1}{4}$ carbon fibre choppings
Fabric FM 5670
Diced fabric $\frac{1}{2}$ x $\frac{1}{2}$ inch square</td><td>All IRC rayon</td></tr>
<tr><td>Random fibre CFC$\frac{1}{4}$
Chopped squares CCA 2-$\frac{1}{2}$($\frac{1}{2}$ in x $\frac{1}{2}$ in.)</td><td>All ENKA rayon</td></tr>
<tr><td>PAN chopped square $\frac{1}{2}$ in x $\frac{1}{2}$ in</td><td></td></tr>
</table>
<p>Conclusions reached were that the highest fibre content silicone rubber was probably the best for C 518 propellant but that Irish Refrasil had the least erosion with RS2 propellant. A NAVWEPS formulation of GE 655 was the next best performer and the R155 was the worst. DC 93.104 eroded more with the C.518 than with the RS2 propellant.</p>
</td></tr>
</table>

contd...... on sheet 14

<table>
<tr><th></th><th>Date</th><th>Title</th><th>Reference</th><th>Synopsis</th></tr>
<tr><td>50.</td><td>1976</td><td>Evaluation of carbon/carbon composite nose tip materials</td><td>J.C.Stetson & J.C.Schultz
AMMRC Report CTR-76-34</td><td>Reports results of a programme which sought ablatives for use as plug or shell nose tips of an Advanced Terminal Defence Interceptor (ATDI) with the secondary need to find new materials for the next generation Anti Ballistic Missiles. This assessment used A.F. Dynamics Lab. 50 M Watt arc jet facility at 75-100 atmospheres stagnation pressure or McDonnell Aircraft high impact pressure test unit (166 atmospheres stagnation pressure).

Composites examined were all made from woven fabrics and Ashland A.240 pitch and were densified to 1.90 Mg m^{-3} at 10,000 lb in^{-2} at Fibre Materials Inc. Biddeford Maine before being graphitised in billet form at 2700°C.

Fibres were woven by Fiber Materials Inc. from Thornel T.400(PAN) T.50 or T.25 (both rayon) and Thornel P experimental fibre made from a pitch precursor.

The effects of reinforcing yarn types, weave spacings and weave dimensions of 14 carbon/carbon composites were evaluated to show that materials produced from fine weaves of Thornel 50 rayon yarns in an orthogonal weave configuration could lead to stable symmetrical nose tip shapes and could also provide the thermostructural and bonding load capabilities needed for an ATDI mission. 100% of the virgin filament strength was achieved for composites produced from the experimental P grade yarns whereas only about 60% of this strength was measured for comparable composites for Thornel 50 to suggest that the yarn/matrix bond had improved markedly with this binder. Further investigation was however needed.

A higher erosion resisting material, such as tungsten or thoria, however, is needed as a sub tip to meet a severe thunderstorm condition.</td></tr>
<tr><td>51</td><td></td><td>Nozzle design with pitch precursors</td><td>Paper 76.692 AIAA/SAE
12th Propulsion Conference
Paelo Alto July 1976</td><td>Materials were evaluated by arc plasma tests against their potential application as lining for a space shuttle soild rocket motor application. The 2.5 inch diameter throat HIPPO motor was used in static motor firings for this assessment (it burns for 33 s and develops about 560 lb in^{-2} chamber pressure).

Thepresent design of this throat insulation is nylon fibre/phenolic and canvas/phenolic has also been considered. The carbon/carbon composites considered were:-

<table>
<tr><th>Precursor</th><th>Commercial reference (if given)</th></tr>
<tr><td>Rayon</td><td></td></tr>
<tr><td>Pitch Mat</td><td>Fiberite MXG 1033F, MXG 313P, Hexcel 46 SP08</td></tr>
<tr><td>Cloth</td><td></td></tr>
<tr><td>Hybrid rayon and pitch</td><td>US Polymeric FM 5790</td></tr>
</table>
</td></tr>
</table>

END

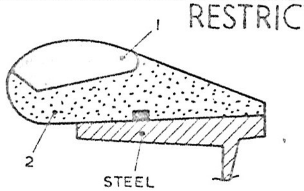
APPENDIX 7

KEY TO INSULATION

OPERATING CONDITIONS

COI - 1
ORBITAL BOOST

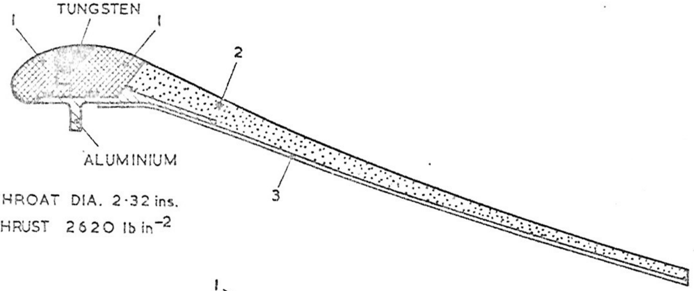
THROAT DIA. 0·54 ins
THRUST 330 lb in^{-2}



1. Polycrystalline graphite.
2. Carbon/phenolic tape.

Flame temp. 2900°C
Burning time 14·6 secs.
Max. pressure 1070 lb in^{-2}
Propellant AP/PBAA/Al

APOGEE MOTOR
HS303A SATELLITE



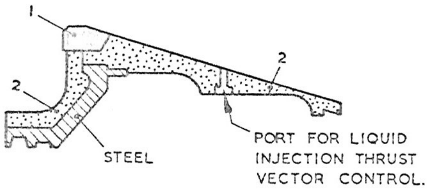
THROAT DIA. 2·32 ins.
THRUST 2620 lb in^{-2}

1 Carbon/phenolic moulding.
2 Silica/phenolic tape.
3 Glass cloth/epoxide.

Flame temp. 3230°C
Burning time 17·8 secs.
Max. pressure 389 lb in^{-2}
Propellant AP/PBCT/Al

ASROC
EXTENDED RANGE

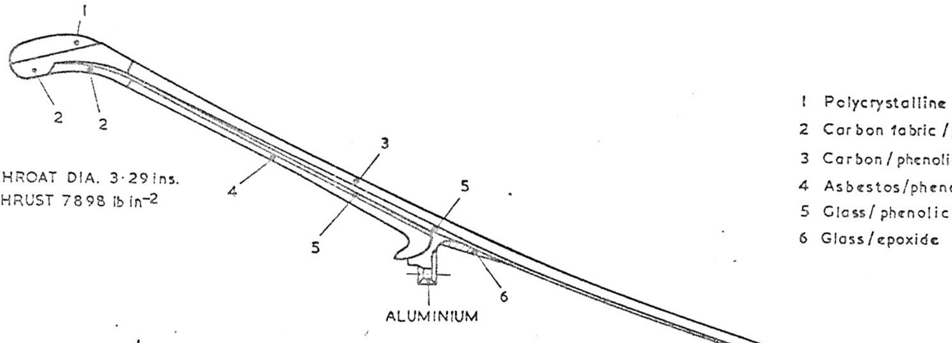
THROAT DIA. 3·26 ins.
THRUST 15,200 lb in^{-2}



1 Polycrystalline graphite
2 Silica/phenolic moulding

Flame temp. 3208°C
Burning time 9·0 sec.
Max. pressure 1350 lb in^{-2}
Propellant AP/PBCT/Al

SURVEYOR
MAIN RETROROCKET

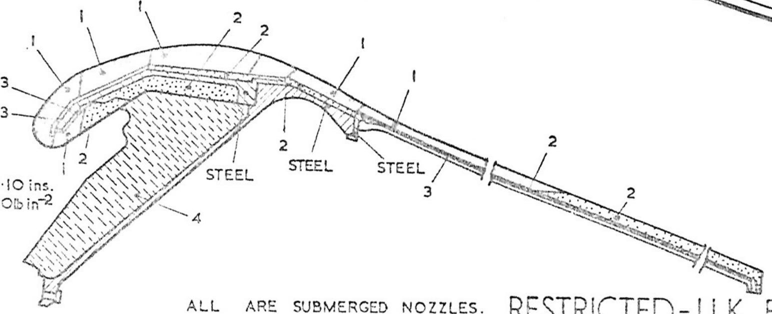


THROAT DIA. 3·29 ins.
THRUST 7898 lb in^{-2}

1 Polycrystalline graphite.
2 Carbon fabric/phenolic rosette.
3 Carbon/phenolic moulding.
4 Asbestos/phenolic tape
5 Glass/phenolic laminate.
6 Glass/epoxide filament wind.

Flame temp. 3046°C
Burning time 40·5 secs.
Max. pressure 556 lb in^{-2}
Propellant AP/PBCT/Al

260 SL 3
DEVELOPMENT MOTOR



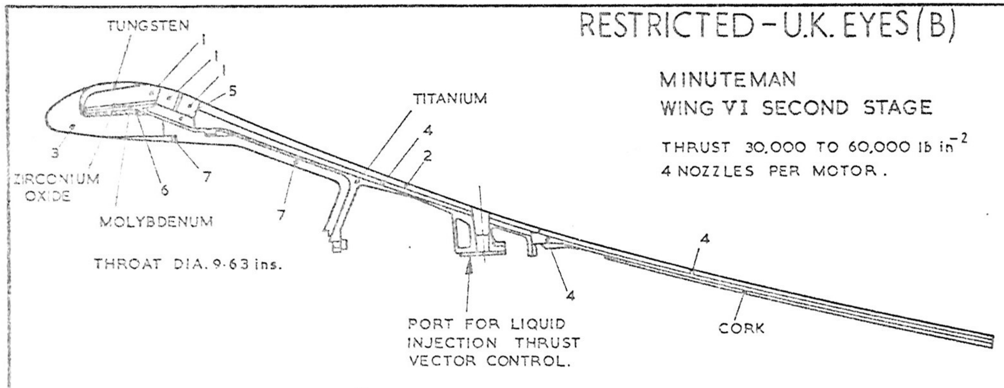
THROAT DIA. 89·10 ins.
THRUST 5,884,000 lb in^{-2}

1 Carbon/phenolic tape
2 Silica/phenolic tape
3 Glass/phenolic tape
4 Elastomer NBR
silica/asbestos filled

Flame temp 3058°C
Burning time 80·3 secs.
Max. pressure 643 lb in^{-2}
Propellant AP/PBAN/Al

APPENDIX 2 SHEET 2B

ALL ARE SUBMERGED NOZZLES.



MINUTEMAN WING VI SECOND STAGE

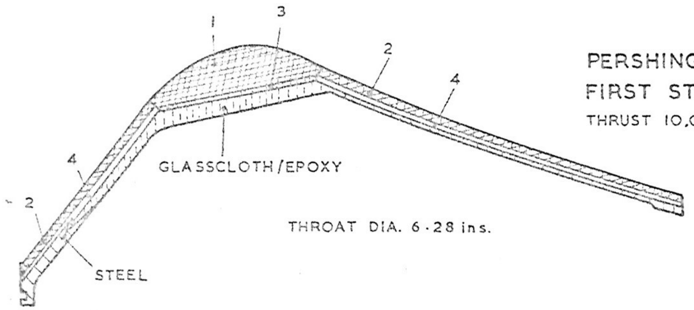
THRUST 30,000 TO 60,000 lb in^{-2}
4 NOZZLES PER MOTOR.

KEY TO INSULATION

1. Polycrystalline graphite.
2 Graphite / phenolic tape.
3 Carbon / phenolic moulding.
4 Silica / phenolic tape.
5 Silica / phenolic moulding.
6 Asbestos / phenolic tape.
7 Elastomer NBR
silica / asbestos filler

OPERATING CONDITIONS

Flame temp. 3149 - 3315° C
Burntime 60 - 100 sec.
Max. pressure 400 - 700 lb in^{-2}
Propellant AP/PBCT/Al



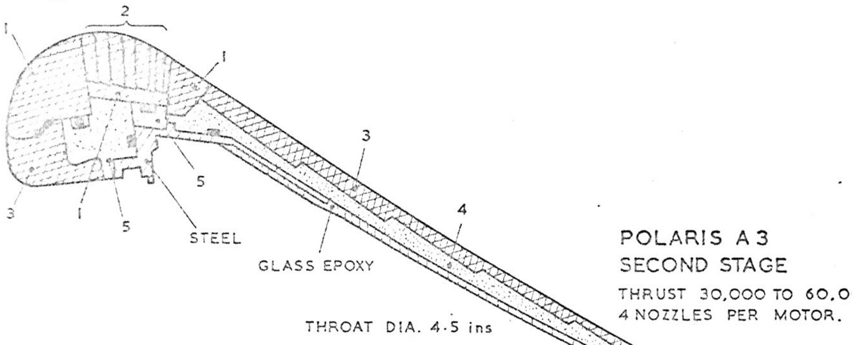
PERSHING FIRST STAGE

THRUST 10,000 TO 30,000 lb in^{-2}

1 Polycrystalline graphite
2 Graphite / phenolic tape.
3 Silica / phenolic tape.
4 Asbestos / phenolic tape

Flame temp. 2982 - 3149° C
Burn time 30-60 secs.
Max. phenolic. 400-700 lb in^{-2}
Propellant AP/PBAA/Al

MINUTEMAN AND POSEIDON HAVE SUBMERGED NOZZLE

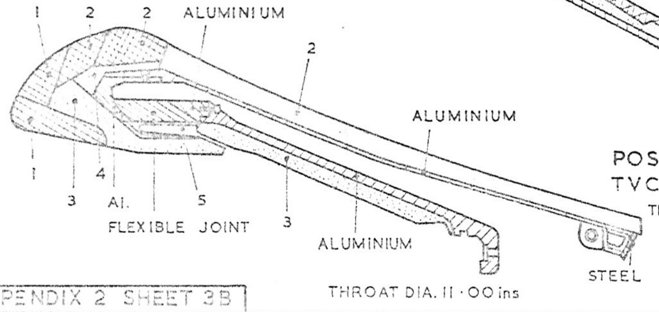


POLARIS A3 SECOND STAGE

THRUST 30,000 TO 60,000 lb in^{-2}
4 NOZZLES PER MOTOR.

1 Polycrystalline graphite
2 Pyrolytic / graphite washers (wedges)
3 Graphite / phenolic tape.
4 Asbestos / phenolic tape.
5 Asbestos / phenolic moulding

Flame temp. >3315°C
Burn time 60 - 80 secs
Max. pressure < 400 lb in^{-2}
Propellant AP/HMX/NC-NG/Al



POSEIDON C3 TVC NOZZLE FIRST STAGE

THRUST 100,000 TO 200,000 lb in^{-2}

1 Carbon fabric / phenolic rosette.
2 Carbon / phenolic tape.
3 Silica / phenolic tape.
4 Silica / phenolic moulding.
3 Silicone rubber.

Flame temp. 3149 - 3315°C
Burn time 60 - 100 secs.
Max. pressure. 700 - 1000 lb in^{-2}
Propellant AP/PBAN/Al

All these missiles were still deployed in 1977	Nature and purpose	Length m	Diameter mm	Wing/fin span mm	kg Weight	MK Speed	Motor Manufacturer
SPARROW III	Short range air to air, all aspect, all weather missile-radar guided (X band) A sea based surface to air version exists.	3.56	200	1000	200	3	Aerojet.General Corporation
SIDEWINDER 1C	Short/medium range air to air semi active radar homing or infra red guided missile. Entered service 1965 mainly against US Navy requirements.	2.84	127	609	84	2	North American Rockwell Rocketdyne Division
PHOENIX	Long range cruise flight high performance air to air weapon, radar homing used on F14 Tomcat interceptor.	3.96	380	914	380	-	North American Rockwell Rocketdyne Division.
CONDOR	Medium range supersonic air to surface cruise missile. Remote TV guidance for fire then launch sequence. An American equivalent of Martel. Designed originally for liquid fuelled motor but changed mid 1969 to solid propellant motor. Production 215 off authorised for 1976/77.	4.22	430	135	966	-	North American Rockwell Rocketdyne Division.
MINUTE MAN II	Intercontinental ballistic missile Site launched solid propellant Wing VI became operational 1966	18.2	Approx. 1600 at 1st stage inter-change		31,750	> 24,000 km/h at burn-out	Aerojet General SR.19-10-1 (Ablative type re-entry vehicle is made by AVCO)
PERSHING I	Nuclear warheaded ground to ground battlefield support missile. Vehicle mounted for mobility. Inertia guidance. Three battalions operative 1970. Production ceased in 1971 but still operative in 1976.	10.5	1,000	-	4,600	3	Thickel Chemical Corporation.
POLARIS A3	Fleet ballistic missile submarine launched, inertia guided. Production ceased 1968 but missile still operative in 1977.	7.55	1,370	-	13,600	-	Aerojet General Corp. and Hercules Inc.
POSEIDON C3	Fleet ballistic missile submarine launched, successor to Polaris A2, A3 missiles having doubled accuracy. Compatible with existing Polaris launch installations. Multiple Independently Targeted Reentry Vehicles warhead. Improved inertia guidance interfacing with a new ships inertia navigation system. Operative on 31 Navy FBM vessels in 1977.	10.36	1,880	-	29,480	-	Lockheed Missiles & Space Co.

APPENDIX 3

Material	Report Reference	Synopsis
GLASS/PHENOLIC	BAJ-T.R.635-1972	A report that mouldings of this type were being used in critical areas of a missile by another country initiated work using short choppings of a chromo methacrylatochloride sized fibre that was available commercially in the U.K. at the time. (Fibreglass AR.16). It was found that high strength mouldings could be produced if the fibre was given a pretreatment with A.1100 amino silane before it was mixed with either a phenolic resole syrup or a powdered novolak resin. The novolak phenolic resin gave the more consistent mixes and it was shown also that a simple tumble mixer could replace a sigma bladed machine with advantage. Mixing times were found to be relatively critical if glass/resin ratios were to be maintained at the required levels. Mechanical properties of moulded test boards were obtained for seven different levels of glass content ranging from 34.5% to 69.4% by weight to show that optimum tensile strength was being obtained with mixes containing between 55% and 70% by weight of fibre. Various fibre content mixes were assessed also by plasma arc torch tests using small hollow cylindrical mouldings. Shop moulding trials were then made to produce end plate linings by compression moulding and blast pipe linings by displacement moulding. All but the highest glass content mix moulded readily but some wear of the gating in the transfer tool was observed after the higher fibre content materials had been moulded. Selected mouldings were tested in static firing tests in the 203 mm SC test motor at Westcott to demonstrate that this type of material had promise especially the 60% fibre content which eroded less than the resinated asbestos material normally used for these linings. Erosion losses fell as fibre content fell but char thickness, and consequently the total affected thickness, seemed to be at a minimum for the 50% fibre content material.
	BAJ-TR.767-1975	The original objective of this work was to establish whether part of the glass fibre might be replaced by another filling to give an improved performance rocket motor insulation; it commenced using Volan treated AR.16 chopped fibre but as its supplier discontinued production during the programme alternatives had to be considered. A newly introduced commercial choppings of a fibre which had been coated with a phenolic compatible size was introduced and in-house choppings of silane treated E, R and S composition glass rovings were also examined. During the work it was established that none of the alternative chopped fibres needed a pretreatment with A.1100 silane to give a high strength test board and that the strength of these boards reflected the strength differences of the original rovings from which the fibres had been chopped. The supplementary fillers which replaced either 10% or 50% pbw of the glass fibre in experimental mixes were alumina powder, asbestos 5D-1 chrysotile fibre, boron nitride powder, calcium carbonate, cobalt linoleate gum, cobalt phosphate, ferric oxide pigment, Fibrefrax milled fibre, glass ballotini, manganese dioxide, nickel phosphate, pumice powder, silicon carbide fine mesh powder and zinc oxide pigment. All were added singly and combinations of them were not considered. Mixes were assessed by determining tensile strength and elongation at break of mouldings and by the Banwell ASTM-E285-70 oxy-acetylene ablative torch test facility. The effect of introducing supplementary fillers was to reduce both the mechanical strength and the resistance of the moulding to the ASTM torch conditions but high strength mouldings could be produced from all the 'all glass filler' formulations examined and were appreciably higher than those obtained for a comparable resinated asbestos material. It was concluded that a glass/phenolic moulding material might be pursued as an alternative for resinated asbestos moulding material as rocket motor insulation and tentative design figures of 'mean minus three standard deviations' were tabulated for formulations that might be considered.
liquid motor	BAJ-PTM.190-1977 (PTM reports are produced for in-house use and are not normally circulated externally).	The Silenka 118 fibre used in previous work had been withdrawn and replaced by another phenolic compatible chopped glass - Silenka A.8071. This report describes an evaluation of this replacement fibre against its use in a moulding compound from which combustion chamber linings for a packaged liquid motor might be produced. Only a 50:50 fibre/resin formulation was considered but the resin used was changed from J.1011H to J.1004H to obtain the faster flowing material needed for this application (the cup flow time was raised to 6 seconds from the previous 13 seconds). This faster flow was found to lead to an increased, and possibly advantageous, fibre flow at one end of the moulded linings during a shop floor evaluation. In view of the possible project application four separate batches of each of the two different resin formulations were produced and assessed for batch to batch variability using consistency within mechanical properties as the criteria. Experimental linings were then moulded for static firing tests in a liquid motor at Westcott. These firing tests were most promising and the moulding material can now be considered further as an alternative for the much more expensive silica/phenolic edgewise tape wound lining used at present in a project motor.

contd....... on sheet 2

cont'd..... from sheet 1.

Material	Report Reference	Synopsis
SILICA/PHENOLIC	Part 2 BAJ-TR.650-1972	Difficulty had been experienced when using an 'all silica' formulation to produce end plate linings by compression moulding (these mouldings were being used as controls in the Part 1 work where asbestos/silica mixes were being studied). Changes were therefore made in the type and also the amount of resin in the mix;. various post curing technique were also examined and pretreating the fibre with an amino silane was studied. Resin contents were reduced from 49.5 pbw to 39.6, 34.6 and finally to 29.7 pbw to indicate that the limit of mouldability of this type of compound was at about a 30% pbw content. Tensile strength fell with decrease in resin content but the higher strength materials would not give crack-free mouldings unless a 4 hour post cure under pressure at 120°C was employed. The silane addition had a beneficial effect and its effect was to increase the tensile strength of mouldings for two differing resin content formulations. Twelve alternative resins were substituted for the novolak phenolic resin used initially and included other novolak as well as resole phenolics, Xylok 210 and an aromatic amine cured DGEBA epoxide. The tensile strength of the mouldings from these mixes varied from 10.5 to 50.5 MPa according to direction of the specimen and resin used and it was concluded that a resin change could be desirable. Most of the alternative formulations were then assessed as miniature blast pipe specimens in the Banwell plasma arc test facility to provide further evidence for a need to change the resin matrix in this type of mix. Although one of the two preferred resins was a resole syrup the other resoles tested were less satisfactory than novolak phenolic resins under this assessment.
	Part of BAJ-TR.768-1975	Five different resins were used to produce 60:40 fibre/resin mixes from 19 mm nominal length silica fibres for a possible use as the combustion chamber insulation in a liquid motor. Assessment was by mechanical properties of test mouldings and by the Banwell ASTM-E-285-70 oxy-acetylene torch test. All five formulations were found to be superior to a commercially available silica/phenolic compound which had at one time been used on this project motor and offered a higher strain compatibility and strength than resinated asbestos material. The compound having the highest strength had poor performance in the torch test but a compromise between these two characteristics could be made and a formulation recommended. Mouldings from all these silica/phenolic mixes failed in a brittle mode and it would seem that this can be attributed to the rapid disintegration of the fibre into a powder during mixing. It is therefore possible that either an 'all glass' or a silica/glass combination might be a wise choice for the project motor being considered.
ASBESTOS/PHENOLIC Improvements to this widely used type of insulation have been under study for several years at Banwell.	BAJ-TR.431-1967 and BAJ-TR.470-1968	These two reports describe actions taken at Banwell following the cessation of supplies of chrysotile asbestos from Rhodesia needed for the commercial production of Durestos RA.51 moulding flock. Alternative materials were produced from three different grades of chrysotile asbestos from Carey Mines, E. Quebec, Canada and evaluated. At the same time a number of different types of mixers were examined and recommendations made that a Lodige Morton machine should be purchased. Initial productions at Banwell were promising and met most of the DTD.5539 requirements. Firing trials at Westcott showed that it was slightly superior to durestos RA.51 when tested as a blast pipe lining in the 203 mm SC test motor.
	BAJ-TR.544-1970 and BAJ-TR.576-1971	An assessment of fibre alingment that exists in simple compression mouldings showed that asbestos fibre in an asbestos/phenolic moulding compound tended to align in the shortest spew direction to give higher tensile strengths and elongation at break parallel to the shorter side of a 114 x 279 mm test board. This directionality was negligible for a square board 254 x 254 mm. The second report describes some early work on the role of the release agent in a resinated asbestos material from which it was concluded that the presence of zinc stearate reduced the moulded tensile strength as it was raised from nil to 3.85% by weight of the mix. When graphite powder was added to the mix to improve its flow characteristics, it was found that the difference in tensile strength within the two directions of the rectangular test board decreased as the graphite addition was raised until it had become 34.7% by wt. of the total mix. Studies were reported also on how prepregs of asbestos yarns could be used to achieve a preferred orientation of the fibre in a composite using flat sheets and also a torroidal winding technique. A blast pipe of this latter type was produced by a stacked ring technique but did not withstand a static firing on the 203 mm SC test motor at Westcott.

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Material	Report Reference	Synopsis
ASBESTOS/PHENOLIC CONTD.	BAJ-TR.677-1973	This report reviews the nature and sources of chrysotile asbestos fibre and describes evaluations made of a number of differing grades of Canadian 'ex the mine' fibres from the Carey (E.Quebec), Cassiar (Brit. Columbia) and Clinton (Yukon) mines. The tests made indicated that a shorter than the 5D-1 grade of fibre used hitherto could be considered because it not only gave comparable strength mouldings but gave a moulding which could be machined to a higher standard of finish. With this background work was commenced to explore the feasibility of producing moulding compounds having a greatly reduced spelk and/or spiccules content, using wet grading techniques that were being developed at Waltham Abbey. In this latter co-operation it was found that fibres which had been highly opened at the mine were less suitable than the normal grades; it also showed that length grading by wet centrifuging was needed in addition to an initial grading by diameter using wet hydrocyclones.
	BAJ-TR.730-1974	Existing resinated asbestos mouldings did not have sufficient elongation at break to withstand the conditions being encountered in a new project motor so a development of a material having a higher strain capability was commenced and is described in this report. Two main approaches were made:- (i) Surface treating the fibre to increase its bond to the matrix resin (ii) Modifying the resin matrix by adding liquid or powdered rubber or by replacing it with a conventional rubber gum stock. Because of earlier unsuccessful work elsewhere on anionic coupling agents for asbestos, approach No.1 was confined to cationic agents and examined a standard and two experimental materials all produced by Dow Corning; they were Z6031, XZ.8-5069 and XC-8-5456. None of these materials gave a moulding having a significantly increased elongation at break. Although oxyazolines were also being considered, evaluation samples could not be obtained. Two formulations were developed by the second approach. One had elongation at break of around 1.7% (almost twice that for Durestos RA.51) and the other about 15%. Both had good resistance to the ablative conditions of the ASTM oxy-acetylene torch test and either was superior to Durestos RA.51 in some aspects of this test. Both materials were formulated from Carey 5D-1 asbestos fibres which had been wet graded by PERME at Waltham Abbey and contained acrylonitrile polymers to modify the phenolic resin. A further formulation (based on a conventional acrylonitrile stock having a comparable nitrile content to the liquid and solid acrylonitrile used in the other two formulae) had about 30% elongation at break when produced to have a 37% rubber content; it was inferior to the other two in the ASTM torch test.
	BAJ-TR.777-1975	Describes further evaluation of wet graded fibres. Although graded Cassiar AK, Clinton CY, CP and CT fibres were examined the main part of the investigations were to compare three large Banwell production sized batches of Carey 5D-1 passing 30 mesh fraction with three similar sized batches of moulding material produced from ex-the mine 5D-1 fibre and also with Durestos RA.51. This latter comparison was made by mechanical and ASTM torch tests. The tensile strehgths obtained for the wet graded fibre batches were similar to those for the ex-the-mine fibres, but were less scattered, whereas the results for the Durestos RA.51 covered a wide range; the highest values in the series were amongst those obtained for Durestos RA.51 in the 'B' direction of the original moulding but mean results in the A direction did not differ significantly from means obtained on untreated or treated 5D-1 fibre. A more consistent behaviour of processed fibre was noted also in the ASTM torch tests which resulted in this material being in the upper part of the scatter bands for Durestos RA.51 for the various parameters determined by this test. Some work was carried out to find out whether there might be any advantage in using a more closely controlled fraction of graded fibre. Moulding compounds were prepared to compare 'passing 30 mesh' fractions of Carey 4T-1 and 5D-1, Cassiar AK fibre with the 'passing 100 retained on 30 mesh' fraction of these fibres; a latter type fraction of Clinton CY was examined also. The use of the narrower cut fraction of the 4T-1 and 5D-1 fibres gave higher strength mouldings but the difference was small for the AK fibres.

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<table>
<tr><th>Material</th><th>Report Reference</th><th>Synopsis</th></tr>
<tr><td>SILICA ASBESTOS PHENOLIC</td><td>BAJ-TR.534-1970
and
Part 1
BAJ-TR.650-1972</td><td>
The earlier report describes an initial development of this type of moulding compound and the second extends this work to include other ratios of the two fibres. The size of batch produced was scaled up in this latter investigation and the batches produced were raised from 0.3 to 9 kg by change of mixer without problem; although the larger bulks were found, generally, to mould to a higher strength in the A direction to that found when using the smaller mixer.
The range of fibre mixes covered by the complete investigation was:-
<table>
<tr><td>% silica in mix</td><td>Nil</td><td>5.0</td><td>9.9</td><td>14.9</td><td>19.2</td><td>24.8</td><td>34.6</td><td>49.6</td></tr>
<tr><td>% asbestos 5D-1 in the mix</td><td>49.6</td><td>44.6</td><td>39.7</td><td>24.7</td><td>29.8</td><td>24.8</td><td>15.0</td><td>nil</td></tr>
</table>
Strength in the A direction of the rectangular test board (the longitudinal) tended to rise with increase in silica content whilst in the B direction fell, and was thought to indicate a reduced orientation of fibre when moulding the higher silica content mixes; there was also some indication that the elongation at break of such mixes had also increased marginally.
Tailpipe linings made from a number of mixes were used in static motor firings of the Westcott 203 mm SC test motor. These tests showed that the amount of insulation remaining after firing did not differ appreciably from comparable figures obtained for the usual resinated asbestos material. Appreciable swelling of the lining was noted, however, for the asbestos/silica mixes whenever the silica/asbestos fibre ratio exceeded unity. At the time, it was concluded that the much higher cost of the silica fibre did not justify further investigations.
</td></tr>
<tr><td>SILICA GLASS PHENOLIC</td><td>BAJ-TR.768-1975</td><td>
Combinations of silica and glass fibre were examined against their use as a possible replacement of the more expensive edgewise wound silica/phenolic tape being used to produce combustion chamber linings for a liquid fuelled motor.
Mouldings produced from hybrids had mean tensile strengths which were generally intermediate between those for comparable all glass or all silica formulations. Using conventional, contoured, tensile test specimens the elongation at failure of hybrids did not differ appreciably from that of all glass or all silica materials but a newly introduced test showed that they might, nevertheless, have possible advantage. In this test a tapered mandrel was forced up the bore of a small cylindrical moulding of the material being examined until failure occurred. Failing load - % diametric strain diagrams produced by this test showed that although an all silica moulding had an enhanced load bearing and strain capability, it failed catastrophically as soon as a crack had initiated. On the other hand a fibrous filler, such as asbestos, allowed cracking to propagate whilst still retaining some load bearing capacity in the composite so it was argued that the addition of a glass fibre as an additional filler in an all silica formulation might have an advantage not shown by the conventional determination of strain to failure which used a unidirectionally stressed specimen.
A silica/glass formulation was therefore included in the list of recommended materials for static motor firing tests.
</td></tr>
<tr><td>SILICON NITRIDE</td><td>BAJ-TR.600-1971</td><td>
A 'state of the art' review report on this material against its possible use as insulation within a liquid motor; it also outlined proposals for a development programme for this application.
</td></tr>
<tr><td>ELASTOMERIC COMPOUNDS</td><td>BAJ-TR.682-1977</td><td>
Twelve different polymers each containing the same level of filler were examined by determining the weight loss and the thickness change of miniature blast pipes exposed to a plasma arc internally. All conclusions must therefore relate to this test. The filler used was an equipart mix of chrysotile asbestos and silica powder with 5D-1 and 7MS-1 grades of asbestos being used as alternatives. The rubbers examined in this way included butyl, chlorobutyl, nitrile, EPDM, neoprene, Hypalon, epichlorohydrin, fluorosilicone, SBR, polyurethane and silicone, and all were examined with an 80 pphr total filler content. Although weight loss was found to be a useful screening method, thickness changes were thought to be a better criterion. Surprisingly all the halogenated elastomers examined - and especially Hypalon - were less satisfactory than the others and butyl was considered to be the best material examined; the EPDM formulation was also highly rated and had a small advantage of low density.
Stronger chars formed when 5D-1 asbestos fibres replaced 7MS-1 powders in the formulations but the variations made in curing systems and degree of cure did not seem to affect the resistance of the compound to plasma arc conditions. The lower nitrile content polymer of the two nitriles examined had the better rating.
Maximum resistance to the test was associated with a high filler content and it was found that the upper limit was below 50:50 pphr by weight of the asbestos/silica fillers and that the 40:60 mix was probably the best all round compromise between resistance to plasma arc and ease of processing.
</td></tr>
</table>

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Material	Report Reference	Synopsis
CARBON WOOL/ GRAPHITE/ PHENOLIC PM173	BAJ-TR.525-1970	Describes the evaluation of a carbon wool/graphite powder/phenolic resin moulding compound from an earlier ad hoc produced mix which had shown promise in static motor firing tests at PERME Westcott despite its extremely porous nature. During this development the resin was changed from the syrup used originally to a powdered novolak to make preconditioning at 80°C before moulding unncessary and the resin content varied. Mixing in a sigma blade mixer was introduced and mixing time in this mixer was investigated. During this part of the investigation it was shown that there was a critical upper limit to the amount of material that could be mixed efficiently at one time; it was much less than might have been expected from earlier work with asbestos fibres. Formulation changes studied included a partial or a complete removal of the graphite constituent as well as introducing various choppings of continuous carbon fibre as a replacement for the carbon wool ingredient (Hyfil fibre was used). Assessments of formulation changes was by a determination of mechanical properties of moulded test boards, simple compression moulding trials and finally static firing trials of end plate and blast pipe linings in the 203 mm test motor at Westcott using RD.2427 aluminised solid charge propellants. Manganese dioxide was introduced as an additional filler in the developed formulation and did not change the mechanical properties of the moulding significantly; firing tests were not made of this mix.
	BAJ-TR.618-1972	As a continuation of the work at Banwell, mixing trials of a selected mix - Banwell Ref.PM.124 - were carried out and established that a Lodige Morton mixer could be used instead of a sigma blade mixer if larger batches were needed. Twelve entry cones for Lapwing nozzles were produced from a large batch mix by compression moulding as a shop exercise into the feasibility of using a moulding to replace the usual entry cone which is machined from a graphic preform. An X-ray examination of these mouldings showed lack of homogeneity within the moulded blank before machining so three components were selected on a basis of 'best to worst' scale for static motor firings. It was unfortunate that these trials were not made, as it had been concluded that a moulding might be an economically attractive alternative if it could be established that it performed satisfactorily in a rocket motor firing.

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5. Originator's Code (if known)	6. Originator (Corporate Author) Name and Location Bristol Aerojet Ltd., Banwell, Weston-super-Mare, Avon, BS24 8PD.
5a. Sponsoring Agency's Code (if known) RME 1/11/117	6a. Sponsoring Agency (Contract Authority) Name and Location Propellant, Explosives and Rocket Motors -Westcott, Procurement Executive, Ministry of Defence.

7. Title

Insulation for use within Rocket Motors - A Review

7a. Title in Foreign Language (in the case of translations)

7b. Presented at (for conference papers). Title, place and date of conference.

8. Author 1. Surname, initials. Evans N.	9a. Author 2.	9b. Authors 3, 4 ...	10. Date pp. ref. March, 1978
11. Contract Number	12. Period	13. Project	14. Other References

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Descriptors (or keywords)

Heat insulation, Rocket Motors, ablation, linings, exit cones, nose cones, asbestos, glass, ceramic, refractories, rentry.

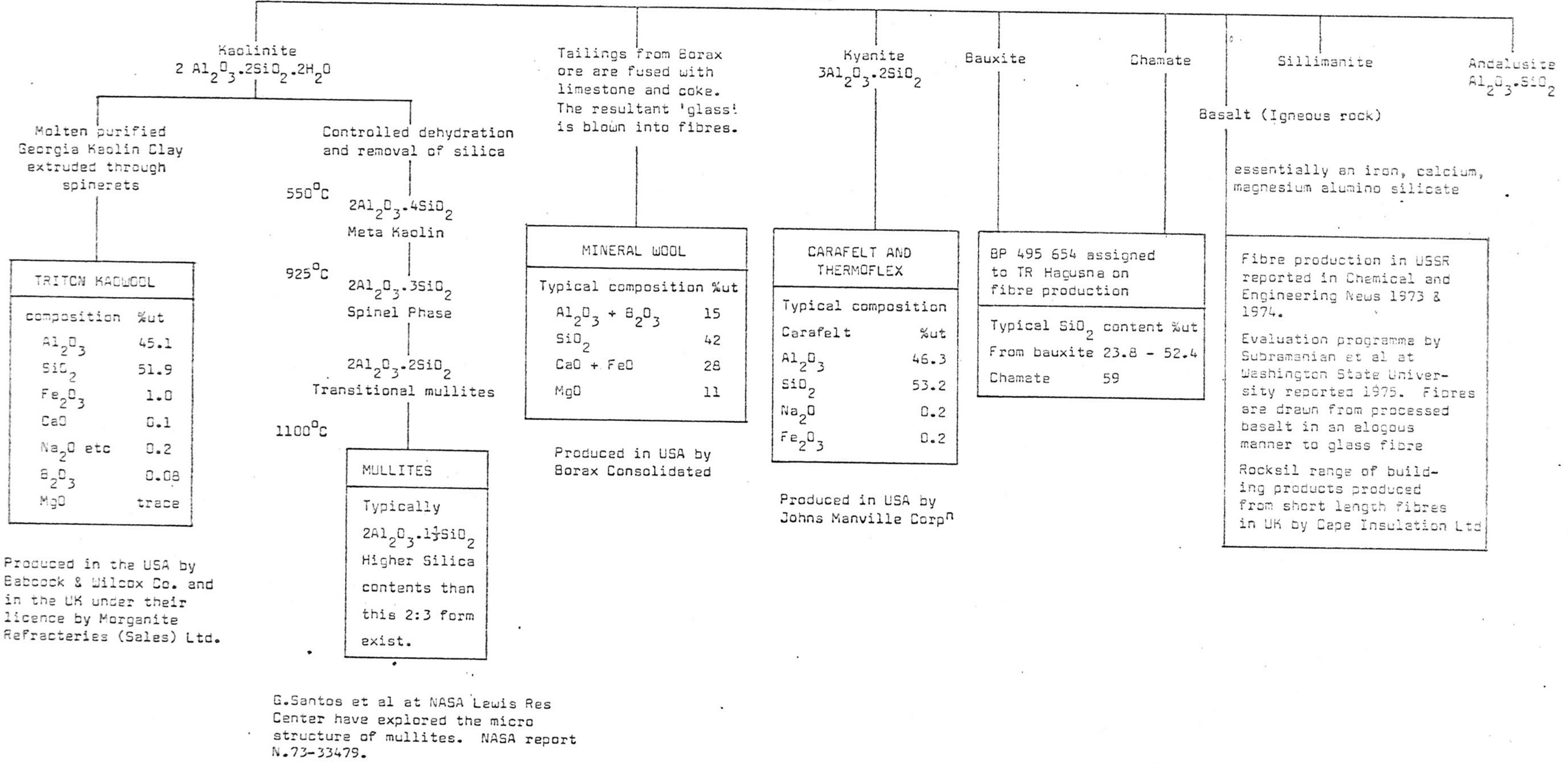
Abstract

A survey of materials that have been used on rocket motor and associated projects, or have been considered for this purpose during the past 20 years.

The information presented is summarised by 7 appendices.

APPENDIX 7
SHEET I

ALUMINA-SILICATES FROM MINERALS



others said to have fibre forming characteristics

Kaolinite
$2\ Al_2O_3.2SiO_2.2H_2O$

Molten purified Georgia Kaolin Clay extruded through spinerets

TRITON KAOWOOL

composition	%ut
Al_2O_3	45.1
SiO_2	51.9
Fe_2O_3	1.0
CaO	0.1
Na_2O etc	0.2
B_2O_3	0.08
MgO	trace

Produced in the USA by Babcock & Wilcox Co. and in the UK under their licence by Morganite Refracteries (Sales) Ltd.

Controlled dehydration and removal of silica

550°C
$2Al_2O_3.4SiO_2$
Meta Kaolin

925°C
$2Al_2O_3.3SiO_2$
Spinel Phase

$2Al_2O_3.2SiO_2$
Transitional mullites

1100°C

MULLITES

Typically $2Al_2O_3.1\frac{1}{3}SiO_2$ Higher Silica contents than this 2:3 form exist.

G.Santos et al at NASA Lewis Res Center have explored the micro structure of mullites. NASA report N.73-33479.

Tailings from Borax ore are fused with limestone and coke. The resultant 'glass' is blown into fibres.

MINERAL WOOL

Typical composition	%ut
$Al_2O_3 + B_2O_3$	15
SiO_2	42
CaO + FeO	28
MgO	11

Produced in USA by Borax Consolidated

Kyanite
$3Al_2O_3.2SiO_2$

CARAFELT AND THERMOFLEX

Typical composition

Carafelt	%ut
Al_2O_3	46.3
SiO_2	53.2
Na_2O	0.2
Fe_2O_3	0.2

Produced in USA by Johns Manville Corp^n

Bauxite

Chamate

BP 495 654 assigned to TR Hagusna on fibre production

Typical SiO_2 content	%ut
From bauxite	23.8 - 52.4
Chamate	59

Sillimanite

Andalusite
$Al_2O_3.SiO_2$

Basalt (Igneous rock)

essentially an iron, calcium, magnesium alumino silicate

Fibre production in USSR reported in Chemical and Engineering News 1973 & 1974.

Evaluation programme by Subramanian et al at Washington State University reported 1975. Fibres are drawn from processed basalt in an alogous manner to glass fibre

Rocksil range of building products produced from short length fibres in UK by Cape Insulation Ltd

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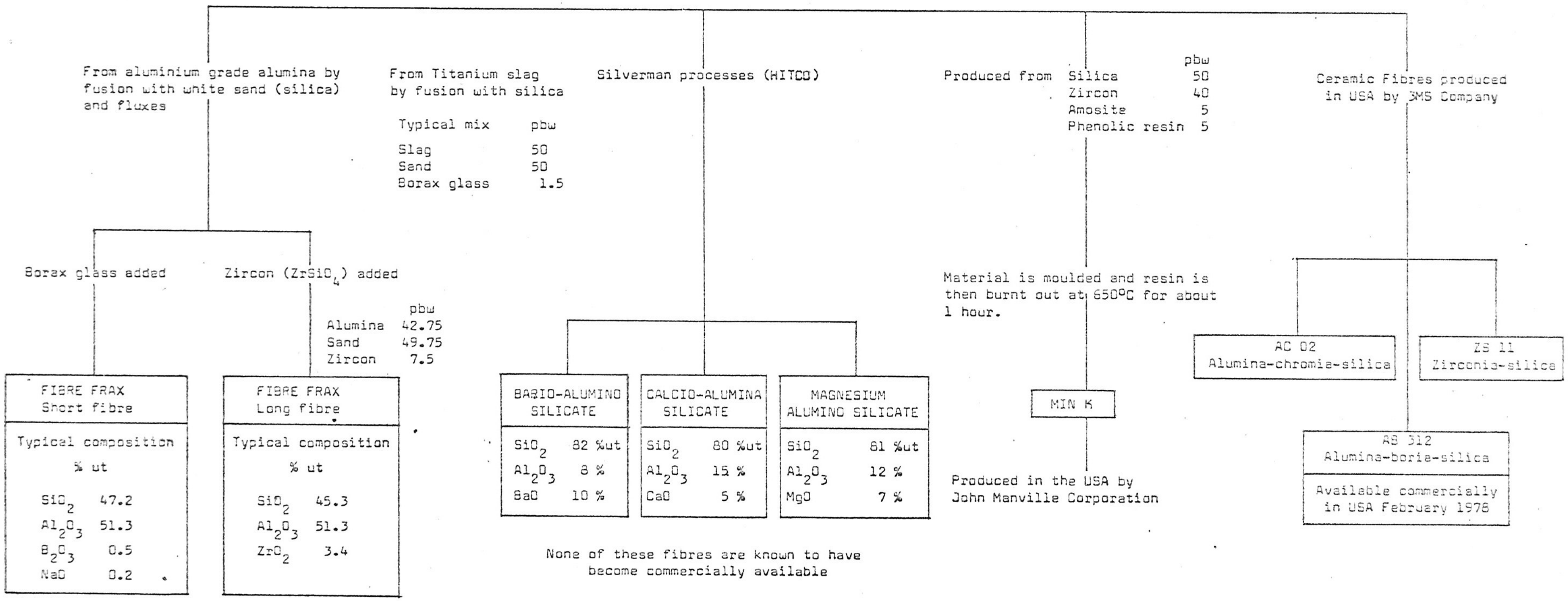
APPENDIX 7
SHEET 2

ARTIFICIAL SILICATES



From aluminium grade alumina by fusion with white sand (silica) and fluxes

Borax glass added

FIBRE FRAX Short fibre

Typical composition % wt

SiO_2	47.2
Al_2O_3	51.3
B_2O_3	0.5
NaO	0.2

Zircon ($ZrSiO_4$) added

	pbw
Alumina	42.75
Sand	49.75
Zircon	7.5

FIBRE FRAX Long fibre

Typical composition % wt

SiO_2	45.3
Al_2O_3	51.3
ZrO_2	3.4

From Titanium slag by fusion with silica

Typical mix	pbw
Slag	50
Sand	50
Borax glass	1.5

Silverman processes (HITCO)

BARIO-ALUMINO SILICATE

SiO_2	82 %wt
Al_2O_3	8 %
BaO	10 %

CALCIO-ALUMINA SILICATE

SiO_2	80 %wt
Al_2O_3	15 %
CaO	5 %

MAGNESIUM ALUMINO SILICATE

SiO_2	81 %wt
Al_2O_3	12 %
MgO	7 %

None of these fibres are known to have become commercially available

Produced from

	pbw
Silica	50
Zircon	40
Amosite	5
Phenolic resin	5

Material is moulded and resin is then burnt out at 650°C for about 1 hour.

MIN K

Produced in the USA by John Manville Corporation

Ceramic Fibres produced in USA by 3MS Company

AC 02 Alumina-chromia-silica

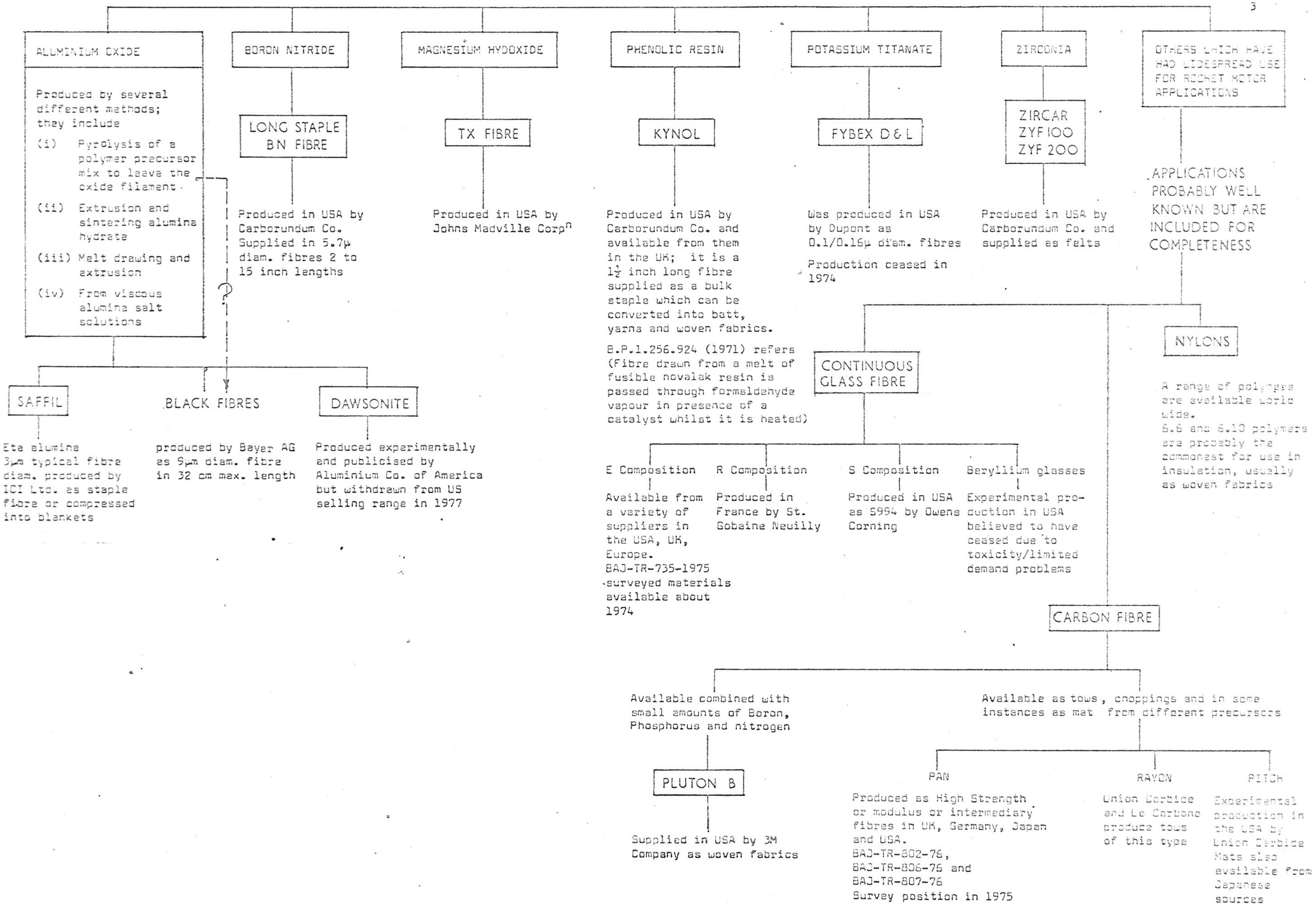
ZS 11 Zirconia-silica

AB 312 Alumina-boria-silica

Available commercially in USA February 1976

APPENDIX 7
SHEET 3

OTHER MAN MADE FIBRES



ALUMINIUM OXIDE

Produced by several different methods; they include

(i) Pyrolysis of a polymer precursor mix to leave the oxide filament.

(ii) Extrusion and sintering alumina hydrate

(iii) Melt drawing and extrusion

(iv) From viscous alumina salt solutions

?

SAFFIL

Eta alumina 3μm typical fibre diam. produced by ICI Ltd. as staple fibre or compressed into blankets

BLACK FIBRES

produced by Bayer AG as 9μm diam. fibre in 32 cm max. length

DAWSONITE

Produced experimentally and publicised by Aluminium Co. of America but withdrawn from US selling range in 1977

BORON NITRIDE

LONG STAPLE BN FIBRE

Produced in USA by Carborundum Co. Supplied in 5.7μ diam. fibres 2 to 15 inch lengths

MAGNESIUM HYDOXIDE

TX FIBRE

Produced in USA by Johns Madville Corpⁿ

PHENOLIC RESIN

KYNOL

Produced in USA by Carborundum Co. and available from them in the UK; it is a 1½ inch long fibre supplied as a bulk staple which can be converted into batt, yarns and woven fabrics.

B.P.1.256.924 (1971) refers (Fibre drawn from a melt of fusible novalak resin is passed through formaldehyde vapour in presence of a catalyst whilst it is heated)

POTASSIUM TITANATE

FYBEX D & L

Was produced in USA by Dupont as 0.1/0.16μ diam. fibres

Production ceased in 1974

ZIRCONIA

ZIRCAR
ZYF 100
ZYF 200

Produced in USA by Carborundum Co. and supplied as felts

OTHERS WHICH HAVE HAD WIDESPREAD USE FOR ROCKET MOTOR APPLICATIONS

APPLICATIONS PROBABLY WELL KNOWN BUT ARE INCLUDED FOR COMPLETENESS

CONTINUOUS GLASS FIBRE

E Composition

Available from a variety of suppliers in the USA, UK, Europe.
BAJ-TR-735-1975 surveyed materials available about 1974

R Composition

Produced in France by St. Gobaine Neuilly

S Composition

Produced in USA as S994 by Owens Corning

Beryllium glasses

Experimental production in USA believed to have ceased due to toxicity/limited demand problems

NYLONS

A range of polymers are available world wide.
6.6 and 6.10 polymers are probably the commonest for use in insulation, usually as woven fabrics

CARBON FIBRE

Available combined with small amounts of Boron, Phosphorus and nitrogen

PLUTON B

Supplied in USA by 3M Company as woven fabrics

Available as tows, choppings and in some instances as mat from different precursors

PAN

Produced as High Strength or modulus or intermediary fibres in UK, Germany, Japan and USA.
BAJ-TR-802-76,
BAJ-TR-806-75 and
BAJ-TR-807-76
Survey position in 1975

RAYON

Union Carbide and Le Carbone produce tows of this type

PITCH

Experimental production in the USA by Union Carbide
Mats also available from Japanese sources

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