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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

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Symposium on the Development of the Plastics
Fabrication Industry in Latin America

Bogotà, Colombia, 20 November - 1 December 1972

VALUE ENGINEERING WITH ENGINEERING THERMOPLASTICS [1]

by

Michael J. Kakos
Pan Amcel Co. Inc.
New York U.S.A.

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SUMMARY

VALUE ENGINEERING WITH ENGINEERING THERMOPLASTICS [1]

by

Michael J. Kakos
Pan Amcel Co. Inc.
New York U.S.A.

Engineering plastics are thermoplastic resins that possess:

1. Predictable properties over a wide temperature range and extended life cycles,
2. Are functional in high heat environments up through 250°C,
   and
3. Have excellent strengths and toughness characteristics.

This combination of properties has enabled design engineers to use engineering plastics in certain items which previously were or could be fabricated in metals, e.g. zinc, aluminum, brass, or thermoset materials, e.g. phenolic, alkyd; diallyphthalate. The resulting products have had improved performance and/or have been manufactured at lower cost.

The thinking process by which a product is improved or altered to enable it's manufacture at a lower cost is called Value Engineering.

Engineering plastics were developed in the late 1930's in the United States with the conversion of nylon polyamide to a plastic molding material.

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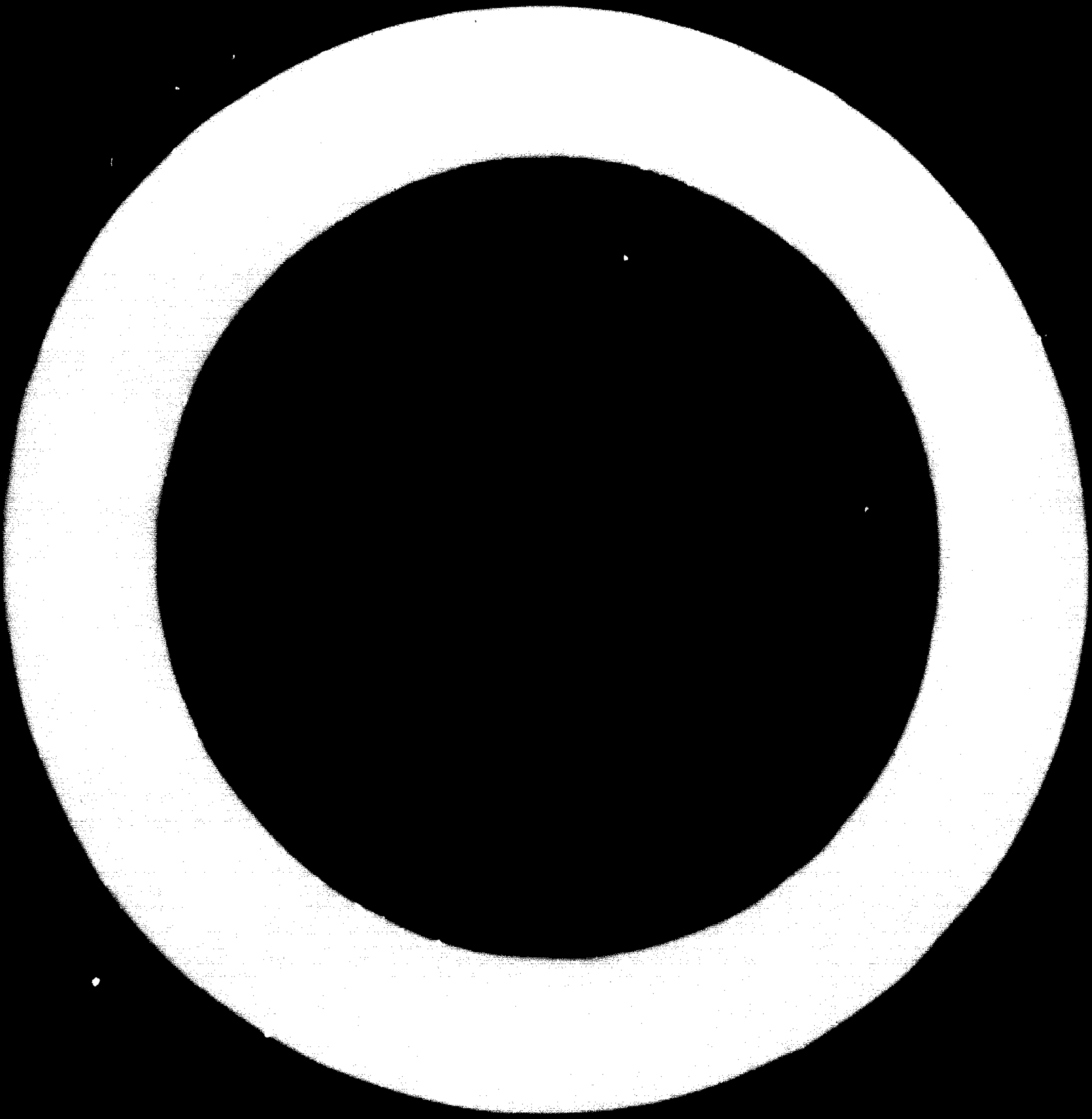


In the 1950's and 1960's the bulk of the interesting new types of engineering plastic resins were developed. These included acetal homopolymer, acetal copolymer, polycarbonate, thermoplastic polyester (polythylene, terephathalate and polybutylane teriphthalate) polysulfone, and polyphenylene oxide among others. These engineering thermoplastics are to be distinguished from commodity thermoplastics such as polystyrene, polyethylene, polypropylene, etc. which are limited to applications where strength, heat resistance and long term productability are not essential.

Throughout the past decade engineering thermoplastics have been pioneered for applications in a cross section of industries including automotive, plumbing, appliances, toys, sound recording tape cartridges, pens and pencils, recreation, etc.

The predictable nature of engineering thermoplastics is the key property which makes them useful for critical applications. Standard design parameters and equations that are used for metal materials can be and usually are applied when designing with the new engineering materials. This is possible because of the predictable long term stability characteristics of these resins.

Cost savings are possible for engineering plastics when compared to items designed in metals or thermosets because of one or more of a combination of factors including lower cost of the engineering plastic (based on volume), cost savings, achieved through easy thermoplastic processability (converting to the molded part), lighter parts made possible because of the inherent strength and lower specific gravity characteristics of the plastic.

Performance improvement in the products fabricated from the engineering thermoplastics may be achieved also. Engineering plastics inherently possess features such as lighter weight, self-lubricating, wear resistance, impact resistance, colorability, and insulation resistance. Some or all of these properties are often useful properties for the fabricated items.

This paper will compare the costs and property analyses for commercial engineering thermoplastic moldings, and the metal or thermoset plastic that was replaced or considered. These case studies have been gathered from many different countries to illustrate that these comparisons are valid in a variety of economies, social and political environment.

Reference is made to the future of engineering plastics. The cost advantage over metals will widen as plastic usage increases resulting in lower material costs, while metal costs continue to rise. Newer and even more sophisticated engineering resins will be developed to answer additional industry requirements and demands.

CONTENTS

I. INTRODUCTION

1. Before the development of plastic synthetic materials in the nineteenth century, metals and other natural materials alone were available for construction of heavy duty, critical, high performance components, articles and structures. Metals including iron, steel, cooper, brass, aluminum, zinc, etc., were and still are for that matter, common materials for items such as hardware, communications, appliances, automotive exteriors and internal components, etc.

2. Metals performed the function they were designed for in most applications. Surely, however, many of the metal applications were insufficient, cumbersome, unaesthetic, unsafe or otherwise left something further to be desired. Engineers sought alternative materials.

3. An early group of plastic materials developed provided some alternatives at the time of their development in the late nineteenth century. These first products were thermoset plastics possessing high temperature resistance but little structural and impact strength. Principal among these were the phenolics. Many of these were flammable; some, in fact, were explosive. Cellulose nitrate, the first plastic, developed as a replacement for ivory in billiard balls was, in fact, later used in munitions for warfare. The development of phenolics by Union Carbide, marketed under the trade-

name Bakelite, was a significant advance of the "art."

4. In addition to the fact that these early plastics were limited in their usefulness as metal replacements by virtue of their physical property drawbacks the means of processing them were restricted to only compression or transfer molding. Not too much flexibility was available in these thermoset systems. In fact, it is the nature of thermoset materials that limits the processability and minimizes the flexibility. With thermoset plastics the plastication mechanism is irreversible. Thermoplastics, of course, may be replasticated an indefinite number of times.

5. The early thermoset materials substituted for many natural materials. For example, as an insulator phenolics were replacements for ceramics or glass. As an insulator and semi-structural item, it replaced wood or metal for appliance cabinets. In many instances these substitutions were accomplished at lower cost.

6. Thermoplastic resins were born as a result of an extension of the cellulose nitrate technology. Cellulose acetate was the forerunner of a large family of thermoplastic resins which were developed for tough, decorative applications, rather than those requiring strength or heat resistance. The big break-through, however, was that thermoplastics opened a new vista in processing techniques and procedures. Now plastics could be injection

molded and extruded. Later other exciting processes were developed including blow molding, film blowing and forging.

7. During the 1930's, however, the engineer's dreams began to be realized following the discovery of synthetic polyamide (nylon) for fiber use. The technicians at duPont developed a polyamide for thermoplastic molded articles. This new plastic had features never before identified with synthetic materials. It had metal like characteristics including strength, heat resistance and toughness; and in addition, it had unique properties such as low density lightweightness, colorability, lubricity, chemical resistance, warmth to the touch, wear resistance, etc. Because of these characteristics nylon was later to be included in a group of sophisticated thermoplastic resins called engineering thermoplastics. Engineers found uses for it immediately. Most of these first applications however, were non-critical items whereby the insulation properties could be utilized such as switches, bobbins, connectors, etc.

8. In the 1950's, scientists invented and developed many more plastics, both thermosets and thermoplastics. For example, thermoset plastics such as alkyds, diallyl phthalates and thermoset polyesters were commercialized.

9. Thermoplastics like styrene, polyethylene, polypropylene and

polyvinyl chloride were also developed. These thermoplastics while originally introduced as expensive products, e.g., 50¢ to $1.50/lb. have dropped in price over the years in a characteristic manner. As their usage has increased economies of scale have been realized. All of these thermoplastics gained wide and rapid acceptance in high volume, non-critical applications. Items such as plastic bottles, crates, housewares, toys, pens and pencils, appliance covers, etc., have increased volume to levels where resin costs have dropped to below 40¢/lb. and many down to 7¢/lb. The basic relationship describing the price/volume sensitivity of thermoplastic resins which has proven historically accurate for the past two decades is:

$$\frac{\text{Volume I}}{\text{Volume II}} = \left(\frac{\text{Price II}}{\text{Price I}}\right)^2$$

These high volume items which have exceptionally wide application because of the non-rigid strength and temperature characteristics are called commodity plastics.

10. Nylon, however, is a more sophisticated plastic from the standpoint of physical characteristics. About 15 years after its development, a group of these sophisticated plastics or engineering thermoplastics began to appear. Each one, it seemed, offered improvement or new characteristics or combinations of features. These were the answers to the per-

sistent requests of design engineers throughout the industrialized areas of the world. Products such as acetal homopolymer, acetal copolymer, acrylonitrite butadiene, polystyrene (ABS), phenoxy, thermoplastic polyester, polycarbonate, polyphenylene oxide and its modifications, polysulfone, etc., were developed within a decade of each other. The popularity of the new engineering thermoplastics is reflected in the estimated 1972 world-wide totals for the individual resins and composite total for the thermosets below:

Plastic Type	Metric Tons
Nylon	136,000
Acetals	59,000
Polycarbonate	46,000
Modified PPO	25,000
Polysulfone	3,000
Polybutylene terephthalate	1,000
Thermoset plastics *	140,000

* Including phenolics, alkyds, dialyzed phthalates

11. Now design engineers have a much wider choice of materials for their new products. They can engineer items more carefully to maximise the features of the products. Further, they can design new products other-

wise not possible because they were too costly due to material limitations and/or design simplicity or because of cumbersome or antiquated, costly fabrication techniques.

12. A new industrial engineering function or discipline has arisen partly as a result of the availability of the engineering resins. It is called "Value Engineering." By definition, Value Engineering is the mechanism of lowering the cost of an item without affecting its function in an adverse manner. A second and lesser known but equally applicable definition of Value Engineering is that it is the improvement of the function of an item without increasing its cost. Later in this paper, we will show examples of each of these functions of Value Engineering.

13. The best definition for engineering thermoplastics is that they are strong, heat resistant materials which have predictable performance over a broad temperature and environmental range. All of the engineering thermoplastics possess these to varying degrees. Additionally, as we mentioned before, all have other distinguishing properties and/or combination of properties that sometimes allow their use in areas where metals or thermoset plastics cannot be used.

14. In Tables I and II, the features of some of the widely known unfilled and reinforced engineering plastics and thermosets are summarized for

TABLE I

PROPERTIES AND CHARACTERISTICS OF
UNFILLED ENGINEERING THERMOPLASTICS AND THERMOSETS

	Acetal Homopolymer	Acetal Copolymer	Nylon Type 6/6*	Polycarbonate	Thermoplastic Polyester(PBT)**	Polysulfone	Phenolic	MF Alkyd
Price (US$/kg)	1.43	1.43	1.43-1.65	1.54-1.76	1.43-1.54	1.98-2.20	.53	.88
Cost/Cu. CM.	.203	.203	.163-.188	.189-.216	.187-.202	.246-.273	.074-.090	.167-.193
Melting Point °C	171°	166°	257°	160°	216°	245°	+	+
Continuous Air Use Temperature °C	82°	104°	52°	116°	149°	151°	-	-
Tensile Strength Kg/CM^2	703	619	774	633	577	717	352	253
Flexural Modulus kg/cm^{2}x 10^3	28.8	26.7	13.4	23.9	23.2	28.1	91.4	112.5
Coeff. of Friction (Metal)	0.15	0.15	0.15	0.38	0.13	0.22	-	-
Heat Distortion Temp. @264psi°C	124°	110°	75°	135°	54°	175°	166°	185°
Specific Gravity	1.42	1.41	1.14	1.23	1.31	1.24	1.4- 1.7	1.9- 2.2
Natural Color	Opaque	Opaque	Translucent	Clear	Opaque	Clear	Translucent	Opaque

* Properties for Nylon 6/6 are measured at equilibrium moisture, i.e. 2.5% moisture

** PBT = polybutylene terephthalate

\+ Decomposes; does not melt

TABLE II

PROPERTIES AND CHARACTERISTICS OF SOME FILLED ENGINEERING THERMOPLASTICS

	20% GR Acetal Homopolymer	25% GC Acetal Copolymer	33% GR Nylon 6/6	20% GR Polycarbonate	30% GR Thermoplastic Polyester	20% GR Polysulfone
Price ($/kg)	1.65	1.65	1.87	2.86	1.72	3.30-3.96
Cents/cc	.257	.266	.258	.386	.261	.455-.546
Melting Point °C		164°	257°			
Continuous Use Temp. °C (Air)	82°	104°	121°		149°	
Tensile Strength kg/cm^2	773	1301	1547	1125	1195	1336
Flexural Modulus kg/cm^2 x10^3	56.3	77.4	63.3	56.3	77.4	70.3
CF (Metal)	.15	.15	.15		0.12	
Heat Deflection Temp @ 264 °C	157°	163°	251°	146°	213°	168°
Specific Gravity	1.56	1.61	1.38	1.35	1.52	1.38
Color	Opaque	Opaque	Opaque	Translucent to Opaque	Opaque	Transparent to Opaque

comparison. Note the added strength, modulus (stiffness), and heat distortion temperature after reinforcing agents or fillers are incorporated in the resins.

II. MATERIAL SELECTION

15. The key feature of the engineering thermoplastics which is lacking in the plastics we have called commodity resins is their predictable nature. Because of it, engineering thermoplastics can be designed into applications using standard design equations such as Hooke's law which have traditionally been used when designing with metals. Creep data, stress-strain curves, apparent modulus, etc., for the engineering thermoplastics, are usually available from the manufacturers of these resins. Typical of the type of data that is available is that shown in Figure 1. Celanese Plastics Company in the United States publishes this apparent modulus data in their technical data bulletin for Celcon acetal copolymer. This data substantiates the predictable nature of Celcon acetal copolymer over a broad range of temperatures. Data of this type is extremely valuable to the design engineer. Before the introduction of engineering plastics, of course, this type of data was not possible.

16. The manufacturer, supplier or distributor of the engineering resins share the responsibility for generating this data. It is essential that it be available during the marketing of the product. Without it, the predictable nature of the engineering thermoplastics cannot be determined.

17. We have discussed engineering plastics as a group. However, within the group of engineering thermoplastics are a variety of materials each somewhat unique to the others. Characteristic differences can be noted in the following typical properties;

- chemical resistance
- moisture absorption
- heat distortion temperature
- dimensional stability
- density
- tensile or flexural moduli
- creep resistance
- impact strength
- fatigue strength

One or more of these will be important for a given application. When designing for a specific application, it is important for the engineer to understand thoroughly all the functions that the new application must perform and the environments and length of time in which it must or will be used. Normally, it is best to consult with the material suppliers after preliminary drawings or sketches for the new design have been prepared. The material suppliers are most knowledgeable about the physical characteristics of their resins and, in many instances, they are almost equally knowledgeable about the characteristics of the competitive engineering thermoplastic resins. They are also knowledgeable about the melt flow and processing characteristics in the resin and, therefore, are in a position to critique the design aspects of the part to be manufactured, in addition to selecting the proper material. When consultation of this nature takes place before molds or dies are cut, expensive mistakes are avoided.

18. The engineer must choose from among a myriad of plastics for the material to be used. In many instances, especially those where the requirements are not too rigid, several engineering thermoplastics will function equally well. As the requirements of an application become more demanding or critical, the number of choices from among the list of engineering thermoplastics is narrowed. The process of selecting the proper one becomes almost one of eliminating from consideration those resins which do not possess the critical characteristics required for the application.

III. PROPERTIES

19. Why choose an engineering thermoplastic over metal or even a thermosetting plastic material? The reasons are as numerous as the property differences that exist between the plastic resins and the metals. Years ago

when material choices were limited to metals, the designer often was forced to overdesign the parts. When one considers replacement of metal with plastic to be impossible or difficult, this should be taken into account. Thus, while the plastic materials lack the strength of brass or the stiffness of zinc or the impact of steel on a thickness for thickness comparison, they can be engineered for many critical applications with careful design to do equivalent or better jobs. For example, in recent years, polycarbonate and glass reinforced nylons have been used in the U.S. and the U.K. for hand held power tool housings. They have successfully replaced die cast zinc and aluminum which were used exclusively for many years. However, now because of the tough, strong and heat resistant nature of the polycarbonate and the glass reinforced nylon, the replacement has been possible. In fact, the change to plastics has been accomplished at a lower cost. Additionally, these plastics provide an improved tool from the standpoint that they are more pleasant to the touch, are electrically insulated for safety, are lighter in weight and have better impact resistance.

20. Plumbing fixtures are yet another new application for engineering thermoplastics. Metals, namely copper, zinc and brass, have dominated this market since the time it was developed many centuries ago. This application also depicts a few more interesting properties of thermoplastic

materials which enables the function of the items to be improved over the metal items. Consider, for example, the non-rust or non-dezincification of plastics when compared to metals. Also, the fact that with appropriate plastics for this application, calcium salt deposits and organic elements of water will not cause problems with plastic plumbing hardware as they will not adhere to the plastic. Combining these advantages with others including more pleasant feel upon touching, smoother operation of the valving mechanism, self-lubrication, low thermal conductivity preventing excess heat build-up, deep molded-in colors to match the decor of the room, etc., reinforces the claim that plastic plumbing fixtures or other hardware items offer improvement over the copper, zinc, or brass items. In addition, in the U.S. and U.K., where this concept has been successfully pioneered, the resulting plastic valves have been manufactured at lower cost than the metal ones.

21. Until the development of the engineering thermoplastics, this plumbing concept was not possible because the properties required to satisfy the environmental demands of the application were not available in thermoset or commodity resins. Properties such as ability to resist hot water continuously without deterioration, creep resistance under hot temperature environments, scratch resistance and resistance to chemical solvent cleaner

attack were important characteristics needed in a plastic to insure a successful plastic application. In fact, with all of these requirements, most of the engineering plastic materials were found to be inadequate. To date, the most successful engineering thermoplastic candidate for plumbing fixtures and related applications is Celcon acetal copolymer. Celanese Plastics Company (Pan Amcel) has now completed 10 years of hot water exposure testing in their laboratories with Celcon. The findings support the claims that the plastic is suitable for hot water applications. The data is available to users and potential users in technical bulletins supplied by the company. Some of the data developed for Celcon and other engineering plastics which possess poor hydrolytic stability will be presented at the UNIDO Conference.

22. Similarly, engineering thermoplastics have improved the quality of printed-circuit edge connectors which have been traditionally molded in thermoset plastics. Diallyl phthalate and glass reinforced or general purpose phenolic have been most commonly used and these have provided the desired stability at high temperatures. However, the thermosetting plastics leave much to be desired in this application despite the high temperature stability and traditionally lower cost as compared to engineering thermoplastics. Because of the nature of thermosetting plastics, processing limitations force production costs for these delicate insert moldings to be

excessively high. Additionally, parts are brittle, especially where thin sections predominate.

23. Engineering thermoplastics have now replaced the thermosetting plastics in this application in the U. S. In this application, as in other critical ones, only one of the engineering plastics provided the required balance of properties and low fabrication cost desired to effect replacement of the traditional thermosetting plastics in this application. For this application, thermosetting polyesters, specifically Celanex polybutylene terephthalate (PBT) was selected. Other engineering thermoplastic resins were candidates in the valve engineering of these connectors including glass reinforced nylon, polycarbonate and modified polyphenylene oxide (PPO). However, since the manufacturer of the connectors searched carefully for the best thermoplastic to satisfy the requirements at the lowest possible cost, these other candidates were eliminated. Here is the analysis used by the manufacturer:

RESIN	ADVANTAGES	DISADVANTAGES
Polycarbonate	Strong/stable	Attacked by solvents
Glass Reinforced Nylon 6/6	Strong/chemically resistant	Dimensionally unstable
Modified PPO	Stable/easy molding	Attacked by solvents

The disadvantages were sufficient to preclude all three after it was found that two other resins, glass reinforced nylon 6/12 and the polybutylene terephthalate had minimal disadvantages and many advantages.

24. The remarkable aspect about this application and these two materials is that although both materials are normally higher in cost than the thermoset materials, the finished fabricated connectors are lower in cost. In fact, the manufacturer in a paper[1] presented to electronics engineers quoted the following relative costs for various plastic materials. They were based on U.S. material and molding costs in 1971:

Material	Relative Cost
Diallyl Phthalate	100%
Glass phenolic	93%
General Purpose phenolic	59%
Polycarbonate	58%
Glass Reinforced Nylon 6/6	53.5%
Modified PPO	53%
Glass Reinforced Nylon 6/12	49%
Glass Reinforced PBT Polyester (Celanex)	38%

As a result of this cost comparison, the PBT has been selected for use by the manufacturer for this application.

[1] "Electrical Connectors Cost and Performance" by Robert Marker, presented at Electronic Study Group Symposium in Cherry Hill, N. J., Oct. 21, 1971 and "Charts Calculate Tradeoffs in PC Edge Connector Costs" by Robert Marker, Electronics June 19, 1972, pp 113, 114

25. Once again, we have an application which represents a good illustration of value engineering. Not only was the cost of the new item in an engineering thermoplastic lowered but in addition, the function was improved. A tougher insulation material replaced one which was brittle and inconsistent in molding characteristics.

IV. COSTS

26. We have discussed the "product improvement" aspect of value engineering. Now we consider the "cost" aspect.

27. There are three components that comprise the cost of a molded plastic item. The first is the cost of the material to be molded and the second is the cost of fabrication of the item. The third component is not usually too obvious. It is a reverse or negative cost factor insofar as it is a cost savings made possible by combining parts or functions with the thermoplastic item. We will treat on these three components more closely in this portion of the presentation as they are an important factor in design and value engineering.

28. First, the material costs component. This is difficult to cover quantitatively here because the prices for plastics as well as metals vary so much from country to country. The factors that cause this variation include distance from the point of manufactur (shipping costs), varying agent commissions involved, especially when the product is imported, varying import duties and

taxes from country to country, inflation or deflation changes in currency and the trends and the local market conditions for the particular product and the competitive products. Let us look more closely at these factors influencing the variation in prices for these resins around the world.

29. Depending on local conditions, i.e., whether or not the product is produced locally or by a nearby friendly neighbor country or that it competes heavily with another domestically available product such as a metal, thermoset plastic or similar thermoplastic, the engineering thermoplastic may be taxed or dutied to some degree. These extra costs must be considered when calculating the overall cost of the molded part. In Brazil, for example, acetal plastic resins have approximately 100% tariffs and taxes applied to the C.I.F. price. As a result, acetals are considerably higher in price in Brazil than in the United States, Germany or Japan, which are some of the manufacturing sites for these resins. Also, acetals are higher in price than "competitive" metals and thermosets and as a result, the market opportunities are suppressed for this engineering resin. Whereas in Germany, for example, over 1/2 Kg. of acetal is used in each German-produced car, there is only 0.1 Kg. of acetal used in the average car produced in Brazil. This means that the opportunities to replace metal and thermosets at lower costs are few. Only in those instances where major cost savings have been possible because of

labor savings in fabrication or design simplicity such as combination of parts or functions have the acetals found acceptance.

30. It is, of course, insufficient to compare costs on a weight basis for various materials. The reason is that metals differ greatly from plastics in specific gravity. Therefore, the most accurate way to compare material costs is on a volume basis. In other words, costs should be calculated on a price per volume basis. Plastic materials are much lighter than most metals and in most areas, they are cheaper by volume.

31. The designer must also optimize his design for a given material to obtain the least volume possible in the item. In many instances, engineering plastics will enable thinner wall sections when compared to the metal or thermoset materials. The reason for this is that metal parts have traditionally been bulky and overdesigned. Thermoset materials are usually heavier to compensate for low strength and brittle characteristics. Engineering thermoplastics, by comparison to thermosets, are stronger and tougher as mentioned earlier.

32. An additional interesting factor to be considered when selecting materials is the pricing trends for plastics versus metals. Natural materials such as the metals tend to increase in price if for no other reason than the cost to mine them is always increasing. Man-made or synthetic

materials tend to decrease in price especially as the production output expands. Generally, this is due to the tremendous price leverage due to economies of scale which apply in the early portion of the life cycle of plastic resins. The price sensitivity of plastics with respect to volume has been recorded and studied for the past few decades. Generally, price and volume have followed the relationship noted earlier, viz.,

$$\frac{\text{Volume I}}{\text{Volume II}} = \left(\frac{\text{Price II}}{\text{Price I}}\right)^2$$

A more obvious picture of this relationship can be seen in Figure 2 where the price/volume values for various thermoplastics have been recorded.

33. In summary, when considering the material cost component of the fabricated item, one should NOT be disillusioned by an apparent high cost for the engineering thermoplastic since other factors in addition to material cost make up the total part cost. When calculating costs remember to base the cost on volume not weight. In addition, price projections should be considered.

34. The second component of the article cost is the cost associated with the fabrication of the item. This is always a confusing area that must be studied carefully.

35. The cost to extrude, cast, machine or forge metals is normally high. With die cast metals, for example, the costs can be excessive especially

if there is considerable trimming, deflashing, deburring, polishing, plating of painting to be done.

36. Thermoset transfer or compression molding is also very cumbersome by comparison to thermoplastic injection molding. Thus, significant cost advantages are generally associated with the less complicated, more advanced thermoplastic molding process. Add to this the fact that the thermoplastic's rejects, sprues and runners can be recycled whereas the thermoset materials cannot.

37. One more consideration regarding fabrication is the flexibility inherent in the processing of the engineering thermoplastics. In addition to injection molding, thermoplastics can be readily extruded, forged, blow molded, and rotationally cast. While no direct cost comparison can be made to some similar processing technique for metals and thermosets, it is important to note that this flexibility provides inexpensive alternatives to fabricating items otherwise more difficult or impossible to form in metals or thermosetting resins. A price tag has no meaning when the alternate materials cannot be fabricated into the desireable item.

38. The more difficult, cumbersome or time consuming the fabrication process, the more sensitive the fabrication cost is to the cost of labor. Long cycles or extra detail work will require more expense. The expense

will be a function of the labor costs in that shop, state, industry or country. Long molding cycles can be tolerated in low labor rate countries such as Latin America and the Far East, whereas they become quite costly in the high labor countries such as America and certain areas of Europe. This factor, therefore, of fabrication cost becomes more advantageous to the engineering thermoplastics as the cost of labor increases.

39. The third area in the cost analysis of a fabricated part is one which is especially key when engineering thermoplastics are to be considered as a material candidate. It is the flexibility to design parts in a manner which enables more simplicity via the combination of parts or functions for the application. There are many examples available but, perhaps the classic one is the value engineering of a garden spray jug. The complicated hand squeeze spray mechanism assembly contained 44 metal parts including cams, springs, gears, etc. After redesign, in which acetal was selected, because of chemical resistance over other candidates, the mechanism contained only 18 parts. This was possible because many of the functions of the individual components were combined in lesser number of acetal parts. The result to the manufacturer was an increase in demand for the jug because he was now able to price it lower since his manufacturing cost was reduced by 60%.

40. A simpler example of part combination is demonstrated in the spring mechanism of a new ball point pen manufactured in Argentina and Brazil. In this item, the costly metal spring and lock button has been replaced by one molded in acetal. The combination of the parts into one part was made possible by taking advantage of the resilience, memory, creep resistance, and fatigue strength of the acetal. This combination of properties is unique to the acetal thermoplastic resins.

V. CASE HISTORIES

41. The best manner to explain the advantages, limitations, material selection, mechanism, etc., is to review case histories where an engineering thermoplastic has been designed into an application. Thus far, we have reviewed the properties and cost of engineering resins in general. These three case histories will emphasize the property advantages of the resin selected, the process by which it was selected and the cost reduction and/or improvement that resulted by choosing it over a competitive engineering resin, thermosetting resin or metal.

Case History No. 1

Electrical Components for Home Appliance - Canada

Three components were switched from phenolic to glass reinforced polybutylene terephthalate (PBT) based on performance and cost.

A. Performance

Strength - tensile and flexural strengths are up to three times that of phenolic resins.

Impact - The tendency of phenolics to chip and break is directly attributable to the extreme low notched impact value. The PBT resin is four times better in impact resistance than the specified phenolic.

Deflection temperature - PBT is 100° F higher than phenolics.

Electricals - glass reinforced PBT is superior to phenolics with volume resistivity being significantly higher. In addition, PBT resin retains this good performance during the life cycle of the parts which can be exposed to varying moisture and temperature environments. Phenolic's electrical properties deterioriate rapidly under similar conditions.

B. Cost

Wall thickness of the three parts were considerably reduced upon material change from phenolic to PBT.

	Thickness Reduction
Part (1)	30%
Part (2)	40%
Part (3)	37%

Wall thickness reductions were possible because of the greater strength and impact properties for the PBT. Consequently, molding cycles were reduced by 50% for all three items. Although the phenolic was priced lower at U.S. $0.60/Kg. than the glass reinforced PBT at U.S. $1.71/Kg., the manufacturing costs were lower for the PBT parts by 36%, 25% and 12%, respectively. Cost reduction was made possible because of:

1. Less material
2. Faster molding cycles
3. Less rejects in assembly due to greater integrity of the PBT
4. Reuse of regrinds is possible with the thermoplastic PBT

C) **Conclusion:**

PBT when substituted for phenolic in these electrical components yielded lower cost items with improved properties.

Case History No. 2

Water Cistern Valves - Finland

Cistern flush mechanisms have traditionally been constructed in brass, bronze, copper or other metals. With the availability of hydrolyticly stable acetal thermoplastics in the early

1960's, many cistern manufacturers replaced metal with acetal. Resulting mechanisms have been equally efficient as the metal precursors. However, manufacturing cost has been reduced. A further advantage of the acetal system has been the lighter weight of the resulting units. This reduces shipping costs.

A. Performance

Acetal plastic cisterns have been available in the United States and Australia. More recently, a manufacturer in Helsinki, Finland, introduced a line of acetal cistern valves.

The new acetal components have no sharp corners and are pleasant to handle. The acetal parts are as dimensionally stable as the bronze parts, but they have the advantage that they do not corrode. Further there is no fouling of the acetal components as lime (Calcium salts) and organic deposits will not form on or adhere to them.

The use of plastics has meant a significant reduction in the weight of the complete assembly and this is another advantage for the manufacturer especially when packing and transporting large quantities.

B. Cost

The old bronze valve consisted of two castings which required a lot of machine work before they could be assembled. Six holes required screw threads, and reaming. Finishing work was needed in the water-ways of the lower part of the valve. Threads and plain holes on the acetal components are provided during the molding process to within the required tolerances and assembly is easier because the water delivery attachment is fitted by means of molded-in lugs which locate in one turn instead of by a threaded attachment on the metal valve which required many turns.

The substitution of acetal for the expensive bronze and the elimination of the expensive machining operations effects the cost savings for the plastic item.

C. Conclusion

Value Engineering of the metal cistern resulted in an improved item which was reduced in weight and cost.

Case History No. 3

Automobile Exhaust Emission Device - United States

The United States has pressured the domestic automobile manufacturers and foreign import producers to provide emission control systems on new cars. These new controls require new technology by the automobile engineers and new materials for the unique designs that are required.

A. Performance

By combining two dissimilar, chemically resistant engineering thermoplastics, nylon and PBT, a leading U.S. automotive manufacturer has reduced the amount of friction between the functional parts to a minimum in a newly designed emission system. As a result, a smoother shifting valve has been developed and this helps reduce smoke for the new exhaust emission control system. The new valve replaced a solenoid valve, speed switch and wiring harness operated by oil pressure from the automatic transmission governor. The new 3-way valve vents the vacuum advance unit of the distributor to air, thus retarding the timing of the spark during idling and low speeds. At high speeds, the valve switches the vacuum advance unit of the distributor to manifold vacuum to advance the spark. The result in both cases is a cleaner engine and lower exhaust emissions. The valve's modulating control also produces a smoother shift into high gear without uncomfortable power surging. Since the valve is exposed to gasoline vapors and oils only materials resistant to automotive chemicals could be selected for this application.

B. Cost

By replacing costly metal fabricated parts and by combining a number of functions of several metal parts, the new plastic valve is now being produced at a 40% savings in production costs.

C. Conclusion

In another illustration of Value Engineering, engineering plastics, this time a combination of two chemically resistant resins, a better functional design was produced and at lower cost.

An infinite number of these case histories have been documented by the engineering thermoplastic producers.. They are available in many end uses upon the request of interested design engineers.

VI. FUTURE OUTLOOK

42. Engineering thermoplastics will continue to grow at a rate of approximately 20% - 25% per annum. This rapid growth rate will reflect the in-

creased marketing efforts of the various manufacturers of the resins throughout the world. Particular emphasis will be in the high volume market where the properties of the resins answer current needs or demands. For example, the automotive industry is searching for high temperature resistant, light weight parts which will be utilized in the production of new safety and ecologically sound devices such as seat belt systems, air bag accident prevention systems and gasoline emission controls. Also, the home appliance industry is searching for high temperature insulation materials which are chemically inert and self-extinguishing.

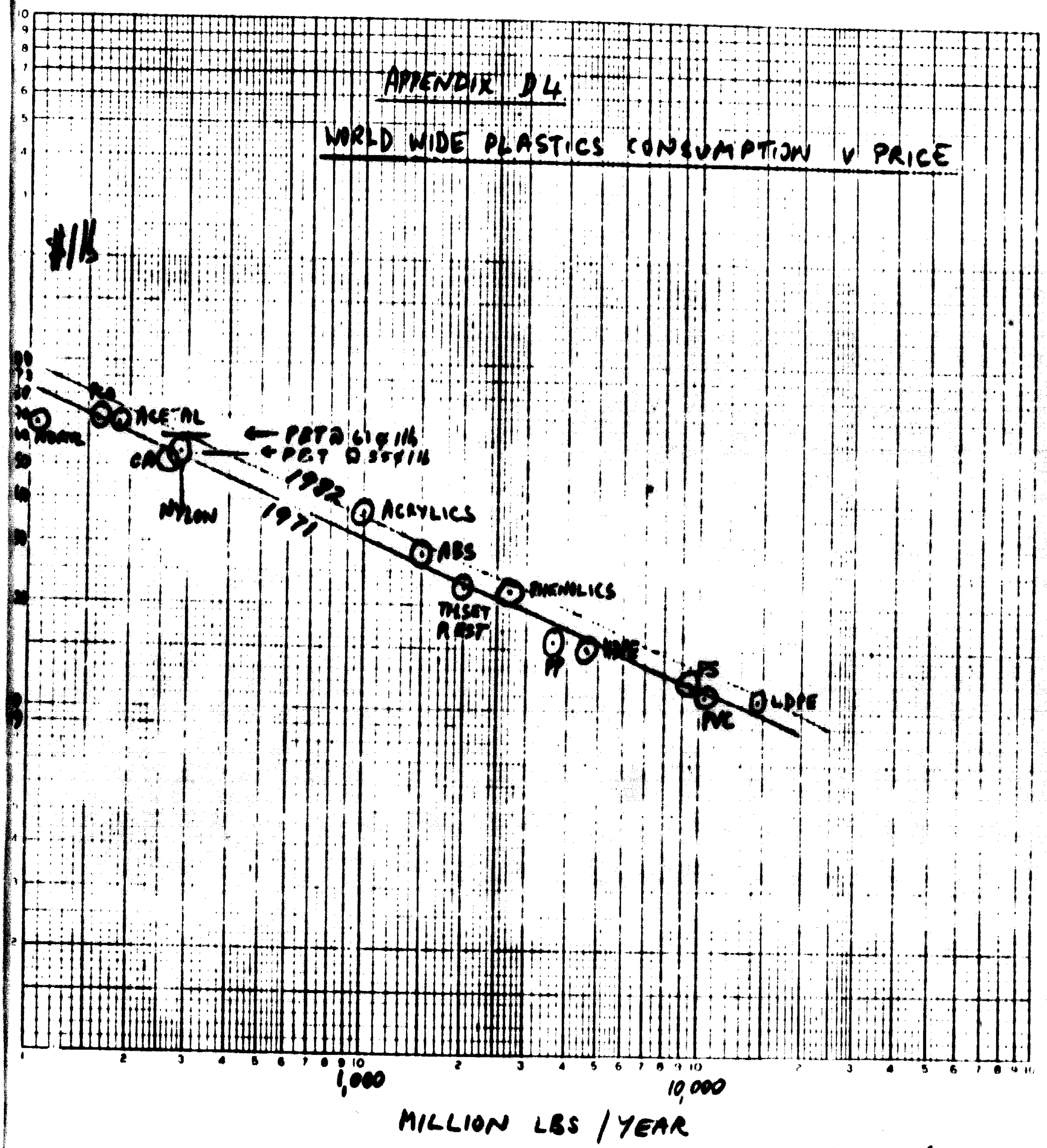
43. Marketing development will also be increased in the developing regions of the world including Latin America where big opportunities for growth exist. Latin America in particular, offers excellent potential for those engineering thermoplastic manufacturers who will invest time, talent, and money for market development, technical assistance, and perhaps eventually local manufacturing.

44. Also, more technological break-throughs can be expected. New resins will be developed for higher temperature environments. Other developments may combine or switch the balance of properties in existing resins.

45. The challenge has been presented to the plastics industry. The requirements have been established and new ones will become known as new

products with exciting new properties are developed.

FIGURE 2.



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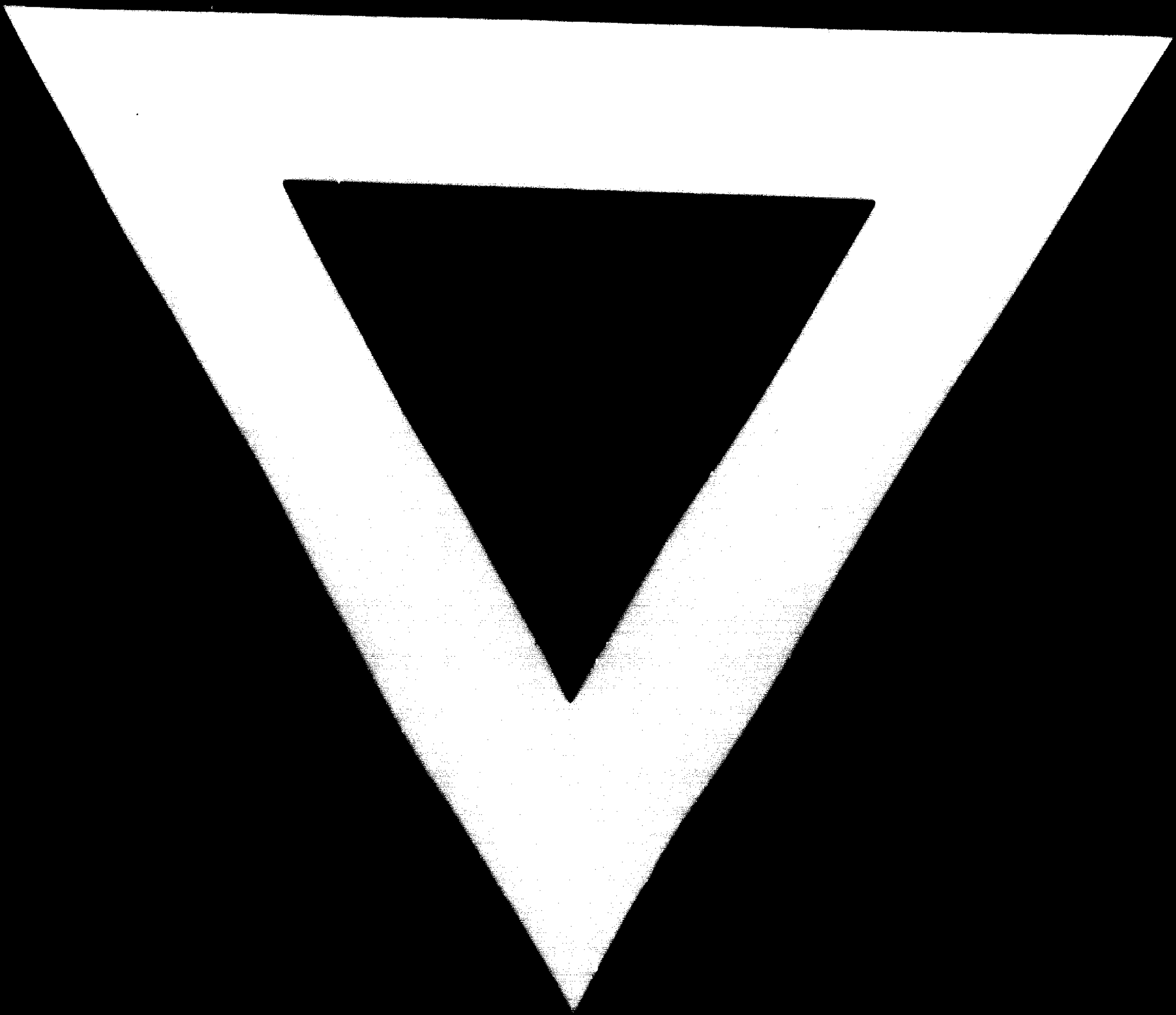
Logarithmic, 3 × 3 Cycles



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