CHEMICAL MACHINING (CHM)

Synopsis

- Introduction
- Etchant
- Maskant
- Techniques of applying maskants
- Process parameters
- Advantages
- Limitations
- Applications

Introduction

- Use of chemicals to remove material is an old art
- Dates back to approximately 4500 years
- During those eras, CHM was more an art form than an industrial tool
- Limited use started in 1930s by the American industry
- In 1940, North American Aviation, Inc, patented a process called Chem-Mill, which was used for the fabrication of aircraft wing panels
- Today, CHM is characterized as a process that uses acidic or alkaline solutions to dissolve materials in a controlled manner for the purpose of milling or blanking parts;
- Chemically resistant coatings (or masks) are used to protect the surfaces that are not to be machined
- Two major CHM processes are:

1. Chemical milling - eroding material to produce blind details – pockets, channels etc.,
2. Chemical blanking – for producing details that penetrate the material entirely (holes, slots, etc.)

Chemical machining

Principle: Chemical attacks metals and etch them by removing small amounts of material from the surface using reagents or etchants

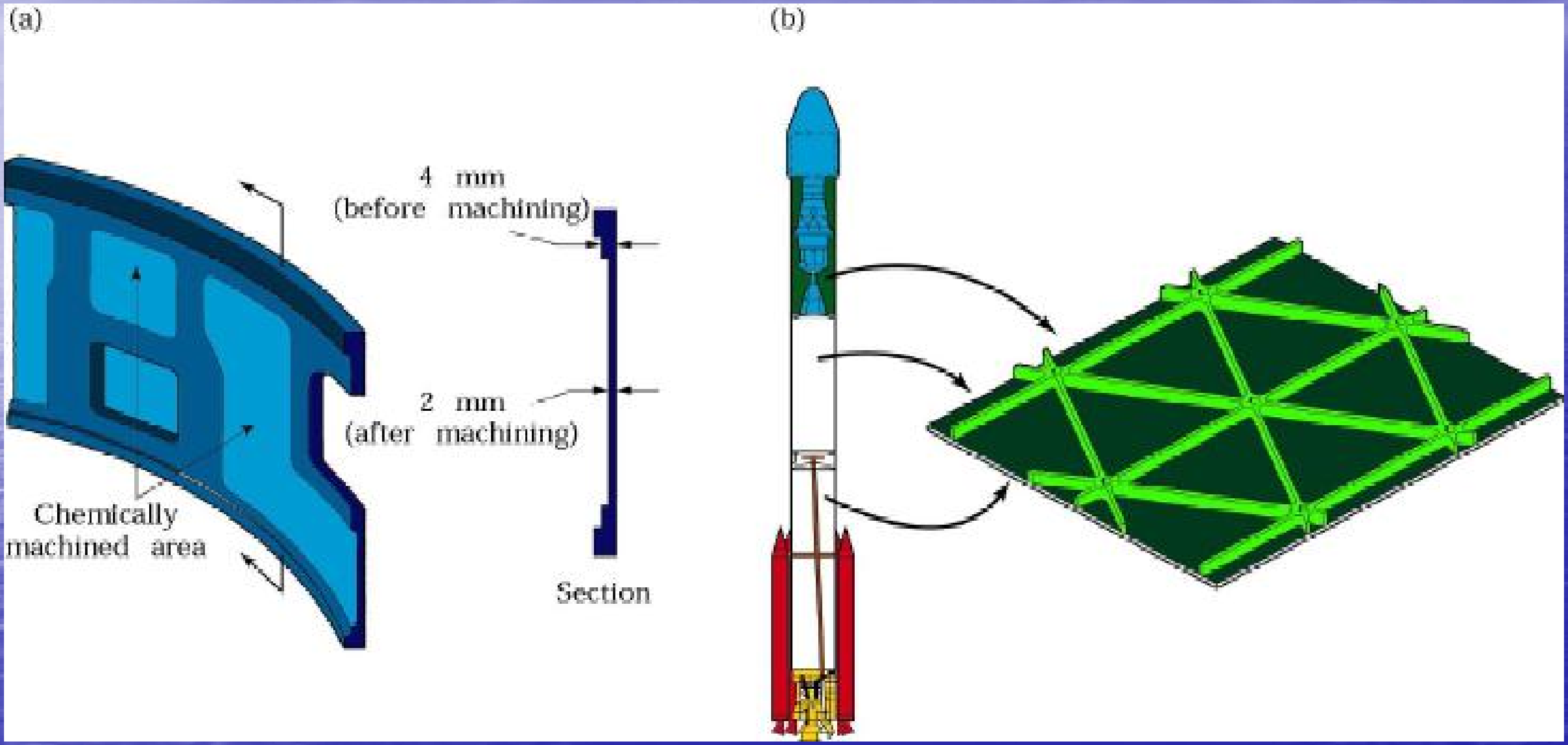
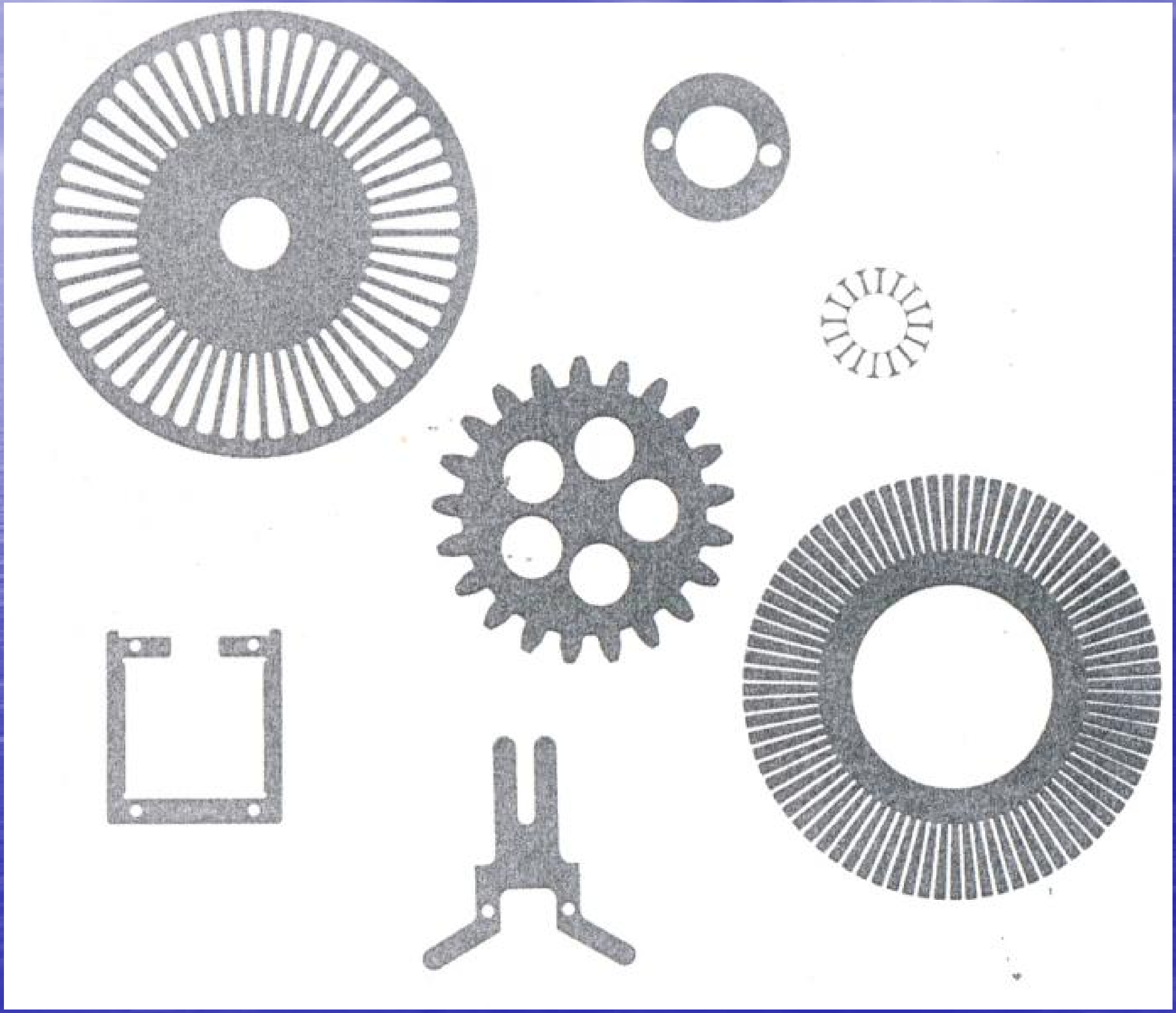


Fig : (a) Missile skin-panel section contoured by chemical milling to improve the stiffness-to weight ratio of the part. (b) Weight reduction of space launch vehicles by chemical milling aluminum-alloy plates. These panels are chemically milled after the plates have first been formed into shape by processes such as roll forming or stretch forming. The design of the chemically machined rib patterns can be modified readily at minimal cost.

Example of parts shaped by blanking



Processing steps

1. Preparing: precleaning
2. Masking : application of chemically resistant material (if selective etching is desired)
3. Etch: dip or spray exposure to the etchant
4. Remove Mask: strip remaining mask and clean
5. Finish: inspection and post processing

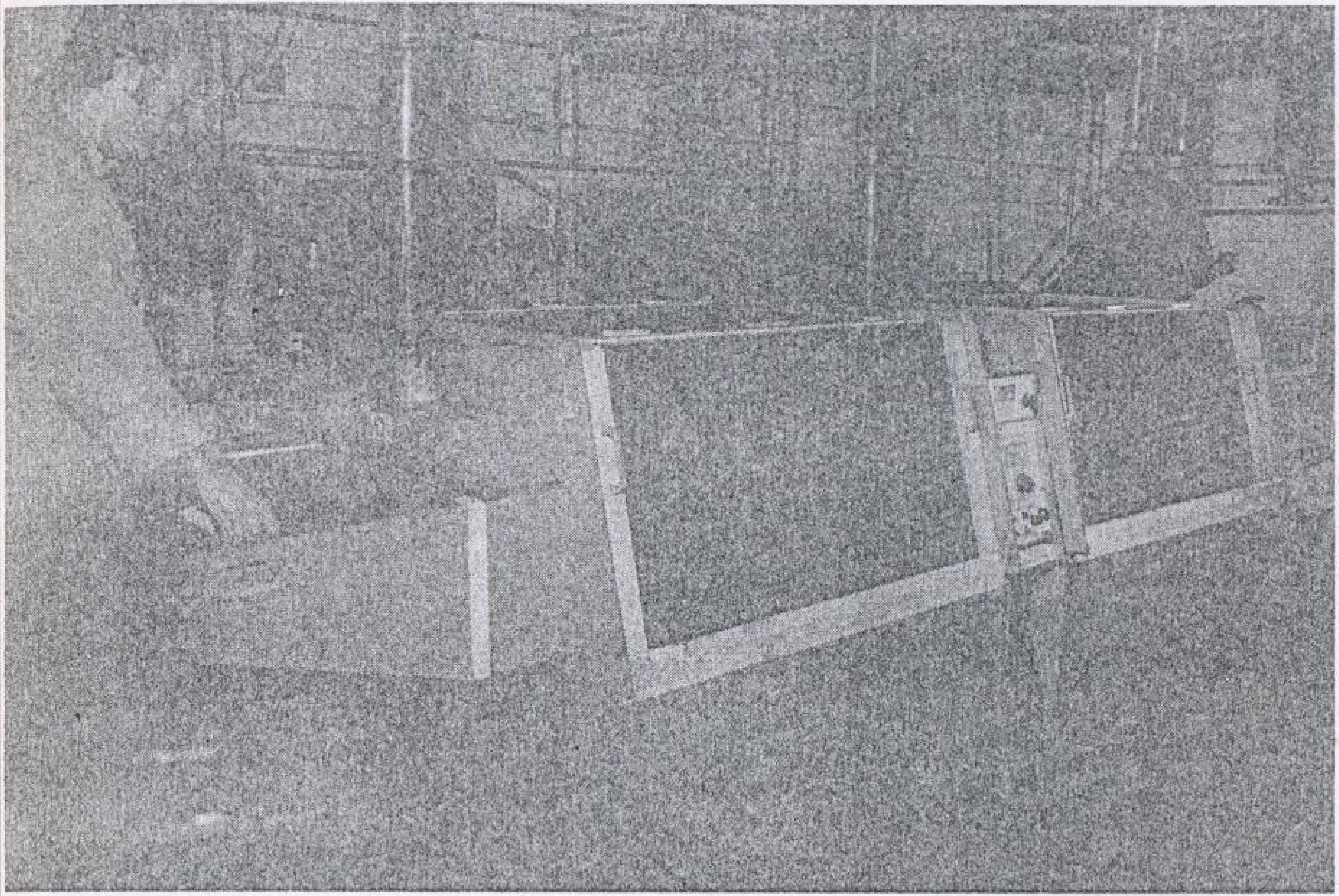
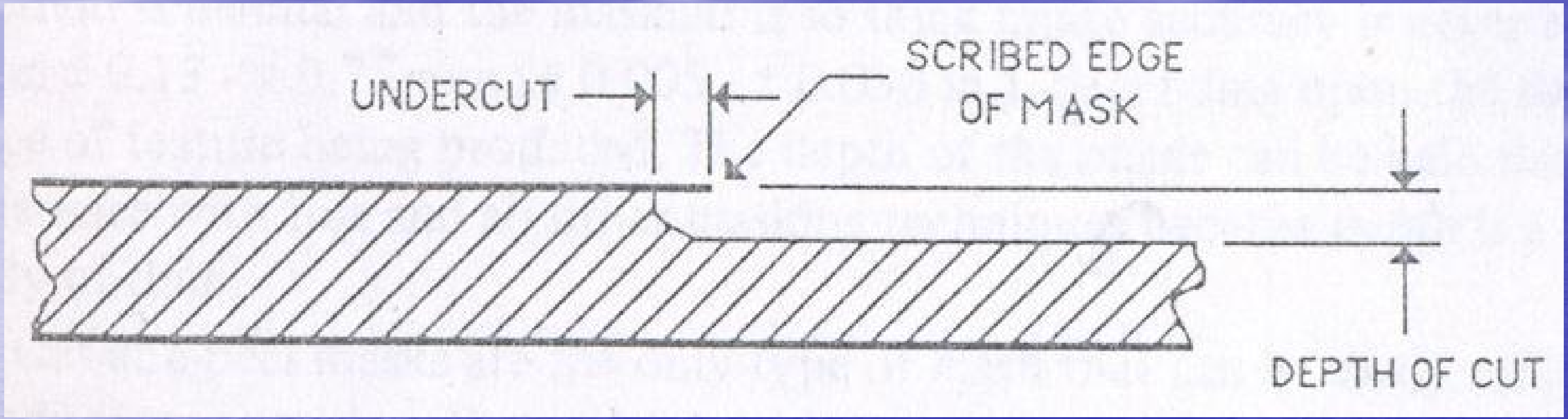


Figure 14.2 Spray-etching system. Workpieces travel through etchant spray on conveyor (*Source*: courtesy, Fotofabrication Corp., Chicago, Ill).

Under cut in CHM



- Amount of undercut that occurs in a particular application is a function of many factors including the depth of cut, the type and strength of the etchant and the workpiece material
- To ensure proper final size of details, it is important to quantify the undercut for a particular combination of variables – etch factor
- Etch factor – ratio of undercut to depth of cut

Etchant

- Purpose: to dissolve a metal by turning it into a metallic salt, which then goes into solution
- Many chemical are available as etchants:$FeCl_3$, Chromic acid, $FeNO_3$, HF, HNO_3
- Etchant selection is based on various criteria

Table 14.2 Etchant Applications and Characteristics

Metal	Preferred etchant	Etch rate (mm/min)	Etch factor
Aluminum	$FeCl_3$	0.025	1.7:1
Copper	$FeCl_3$	0.050	2.7:1
Nickel alloys	$FeCl_3$	0.018	2.0:1
Phosphor-bronze	Chromic acid	0.013	2.0:1
Silver	$FeNO_3$	0.020	1.5:1
Titanium	HF	0.025	2.0:1
Tool steel	HNO_3	0.018	1.5:1

Source: adapted from Bellows, 1977.

Table 14.3 Etchant Selection

Required surface finish.	Some combinations of material and etchant result in the formation of surface oxides, which degrade the finish.
Removal rate	Faster rates lower the cost, but attack the resist bond, result in poor finish, or produce high heat.
Material type	Etchant must attack the material without causing IGA, H_2 embrittlement, or stress corrosion cracking.
Etch depth	Some etchants produce surface finishes that worsen with increasing depth.
Type of resist	Etchant must not destroy resist during the process time.
Cost	Cost of the etchant, maintenance, and disposal must be considered.

Maskant or resist

- Three major categories of chemically resistant masks are available for use in chemical machining
- Selection of proper maskant for a particular application is accomplished by evaluation of the job with respect to six factors – chemical resistance, part configuration, quantity of parts, cost, ease of removal and required resolution

Classification of maskants

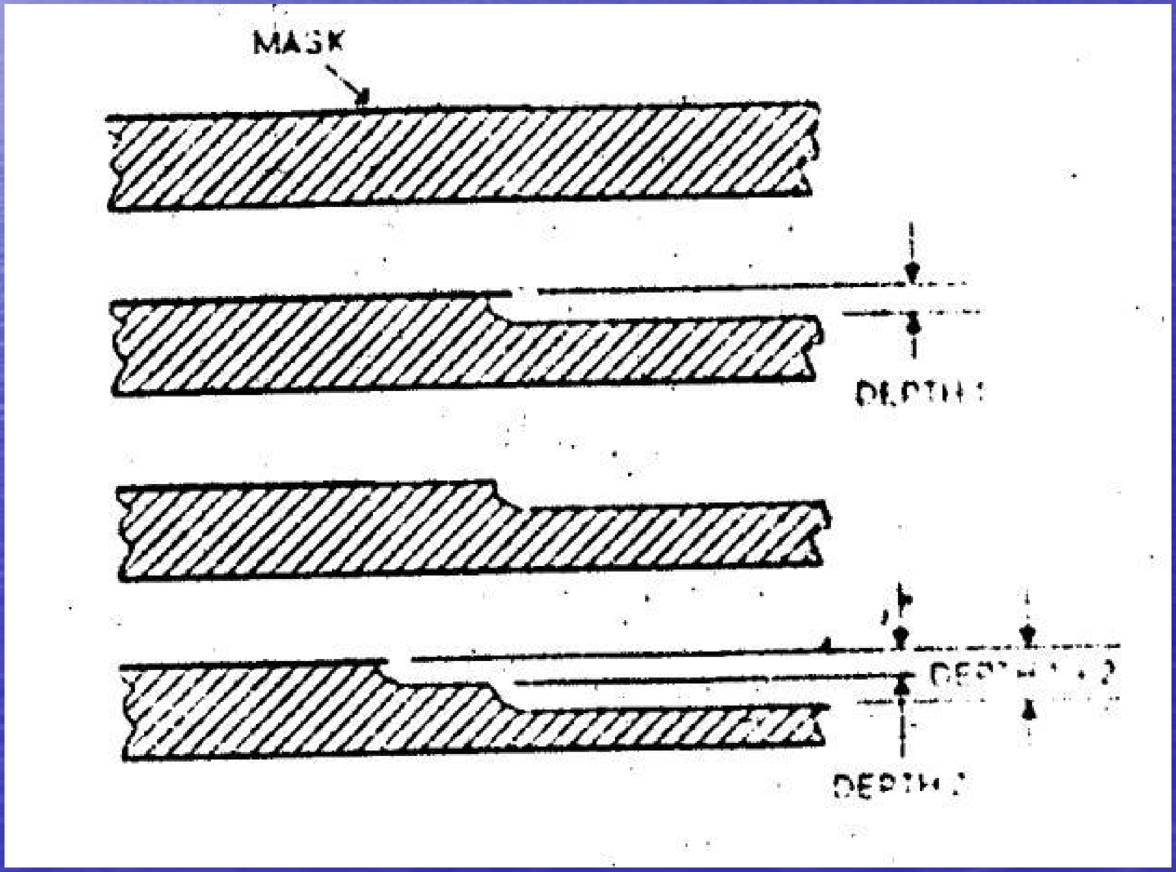
- Cut and peel
- Screen printing
- Photoresist masks

Cut and peel - 1

- Involve the use of relatively thick material which is scribed and removed to create a selective exposure to the etchant
- Neoprene, butyl or vinyl-based material
- Almost exclusively used for chemical milling of aircraft, missile and structural parts and components for chemical industries
- Maskant is applied to the entire part to be processed by flow, dip or spray coating
- Materials are relatively thick in nature, being 0.001 to 0.005 inch thick in dry film form
- Materials are removed from areas to be etched by cutting the maskant with a scribe knife (generally with a template to aid accuracy) and peeling away unwanted areas
- Because of the inherent nature of the maskant and the thickness of the coating, extremely high chemical resistance is achieved, permitting etching depths of 0.5 in. or more
- Generally used where extremely critical dimensional tolerances are not required
- Used for parts that are extremely large, have many irregularities, require depth of etch in excess of 0.05 n and have multiple steps in the removal areas

Cut and peel - 2

- The materials used for maskants afford flexibility in the processing – after a certain area has been etched, additional maskant may be removed so that step etching is possible
- Only type of mask that can be easily rescribed to produce step etching



Screen printing - 1

- Mask application technique that draws on conventional silk-screen printing technology
- A fine mesh silk or stainless steel screen, which has areas blocked-off to allow selective passage of the maskant is used
- The blocked pattern corresponds to the image that is to be etched
- The screen is pressed against the surface of the workpiece and the maskant is rolled on
- When the screen is removed, the maskant remains on the part in the desired pattern
- The maskant is ready for etching after it has been dried by baking

Screen printing - 2

- Screen printing is a fast, economical masking method for high-volume production when high accuracy is not required
- The mask thickness is typically less than 0.05mm and so life in the etchant is relatively short, limiting the etching depth to 1.5mm
- Screen printing is desirable if part size is less than 1.2m x 1.2m; surfaces are flat or with only moderate contours; etch depth does not exceed 1.5mm per side; or when a high degree of accuracy is not required

Photoresist masks

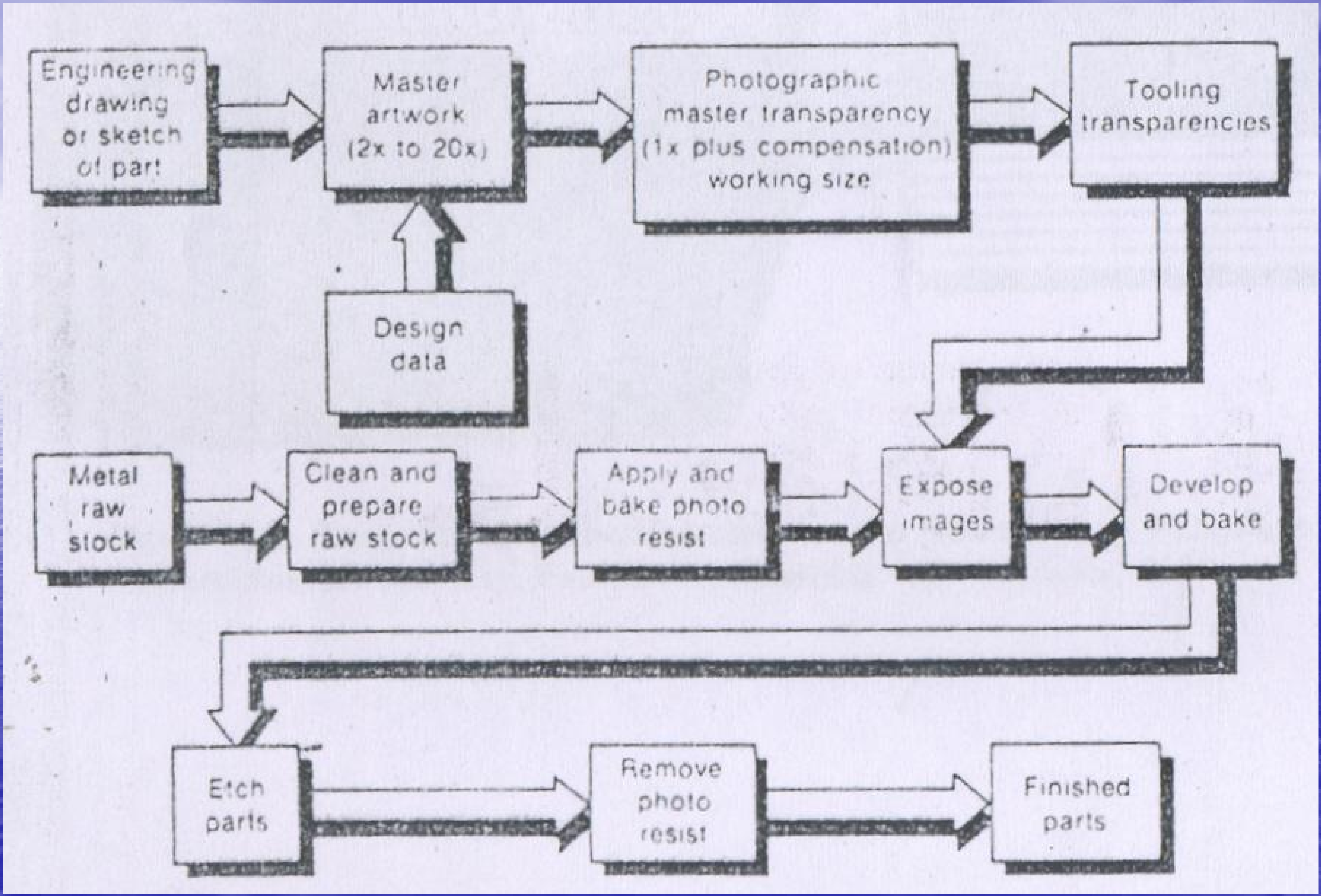
- Photoresist masking is so versatile and in such widespread use that it has almost become a separate nontraditional process
- Commonly known as photochemical machining (PCM), it is used to produce intricate and precise mask on a workpiece
- Capable of producing extremely high detail but lack the chemical resistance necessary for deep etching
- Poor bonding of the resist film to the material being etched, unless the material is very carefully cleaned prior to application of the resist
- Sensitivity to light and susceptibility to damage by rough handling and exposure to dirt and dust, necessitating careful handling and a clean environment for successful operation
- More complicated processing than required by the scribe and peel maskants
- PCM is generally used for:

1. Alternative to conventional stamping when intricate patterns or low production volumes are involved
2. Thin materials
3. Parts requiring dimensional tolerances of the etchant resistant image tighter than ±0.005 in
4. Parts produced in high volume where the chemical resistance of the photographic resists is adequate

- PCM are not generally used for:

1. Depths in excess of 0.05in thick
2. Parts larger than 3ft by 5ft
3. Materials requiring the use of extremely-active etchants that will degrade or strip the photoresists

PCM process


Engineering drawing or sketch of part
Master artwork (2x to 20x)
Photographic master transparency (1x plus compensation) working size
Tooling transparencies
Design data
Metal raw stock
Clean and prepare raw stock
Apply and bake photo resist
Expose images
Develop and bake
Etch parts
Remove photo resist
Finished parts

ıle 14.1 Mask Selection

Factor	Consideration
Chemical Resistance	The thicker the maskant, the longer the exposure time before the maskant is destroyed. Thus deeper etching is possible with thicker masks.
Part Configuration	Some maskants are only applicable to flat parts.
Quantity of parts	The higher the production quantity, the less labor intensive the masking process should be.
Cost	Actual resist material costs vary. Higher-priced maskants are usually easier to remove.
Ease of removal	The maskant is usually removed before part use. Delicate parts require easy removal.
Required resolution	Accuracy varies with maskant and application method. Thicker masks generally result in less accuracy.

Process parameters

- Two most important factors in the process are the maskant and the selection of etchant

Advantages

- **Metal removal is completely stress free**
- **Complex shapes and deeply recessed areas can be uniformly chemically milled**
- **Extremely thin sections can be chemically milled**
- **Metal hardness or brittleness is not a factor**
- **Part size is only limited by tank dimension**
- **Many parts can be chemically milled at one time either by processing a large workpiece before cutting out the parts, or by milling many separate pieces in the tank at one time**
- **Tapered sections can be chemically milled**
- **Most alloys and forms can be chemically milled**
- **Fine surface finishes are produced on many alloys**
- **Extremely close thickness tolerance are achievable**
- **Tooling and tool maintenance costs are low**
- **Cutouts and the periphery of difficult to machine parts can be rough trimmed by etching through the metal, at minimum added cost**
- **Extrusions, forgings, castings, formed sections and deep drawn parts can be lightened considerably by CHM**
- **Company logos, part numbers or other identifying marks can easily be etched into the surface during manufacture at no extra cost**
- **PCM can be used to make one or a million parts, with the same tooling used every time. This allows the engineer or designer to develop their concept from prototype to pilot to full production quickly and easily**
- **PCM process produces burr free components, thus removing the need for costly time-consuming de-burring**
- **Setup and tooling costs are extremely low**
- **Design change costs are low, because only art work is altered – allows great design flexibility**

Limitations

- Fillet radius is approximately equal to depth of cut
- Extremely deep cuts are usually not cost effective
- A homogenous metal structure is normally required for good results
- Welds and castings often produce pitted surfaces when chemically milled
- Process costs depend on the quality of the original workpiece (thickness variation, presence of surface scratches and corrosion)
- It is impractical to make grooves of width less than twice the depth
- Hazardous chemicals used in the process present difficult safety, waste disposal and air pollution problems
- A relatively high level of operator skill is required for PCM
- Suitable photographic facilities are not always available

Applications – Chemical Milling

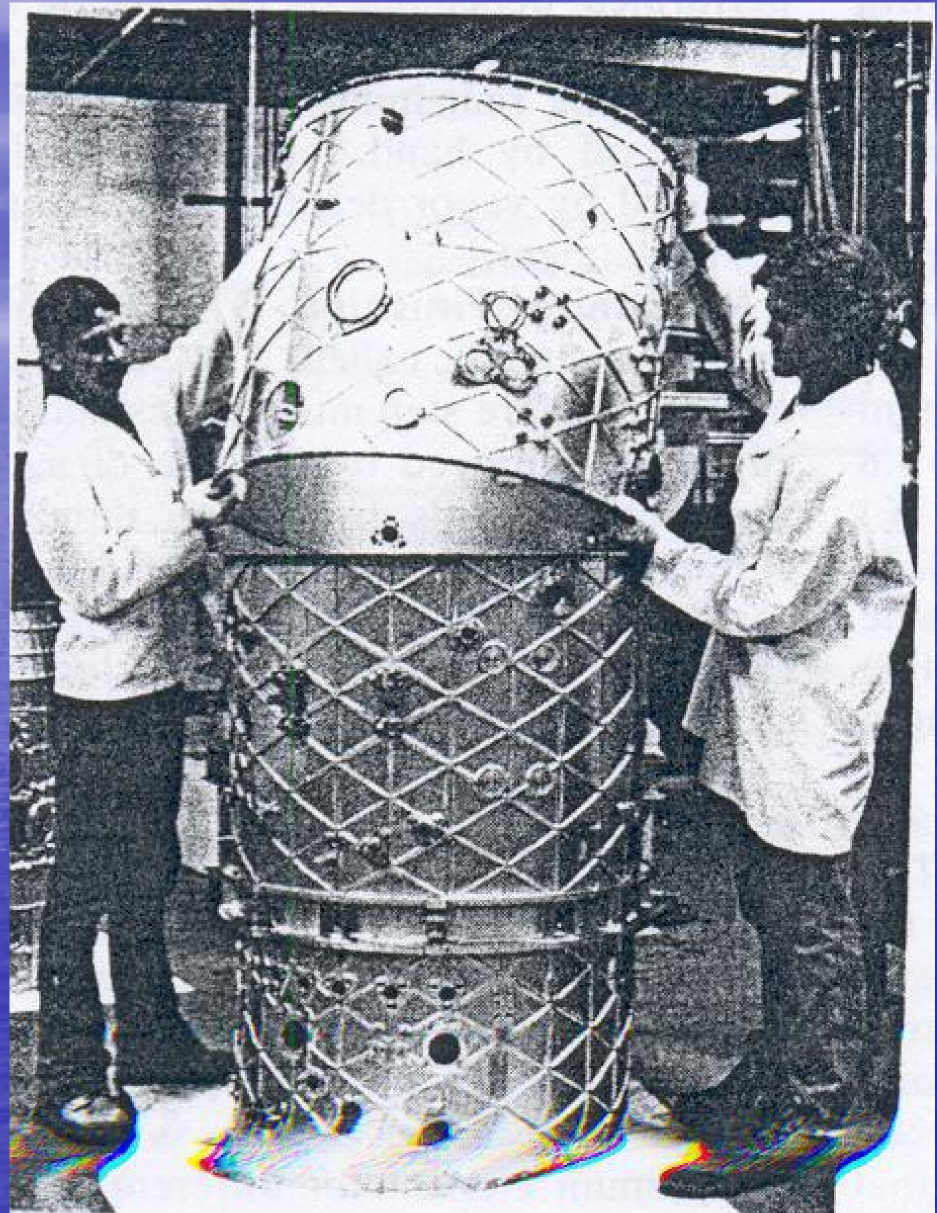
Used extensively to etch preformed aerospace parts to obtain maximum strength to weight ratios:

- Integrally stiffened Titanium engine ducts
- Spray etching a rotating tube for cruise missile launch tubes
- Thinning and sizing of a delta booster tank bulkhead
- Chemical sizing of engine cowl inlet duct skins
- Undercut on clad aluminium
- Removing the alpha case from a Titanium casting
- Elimination of decarburized layer from low-alloy steel forgings
- Elimination of recast layers from EDM

Applications - PCM

It plays a valuable role world-wide in the production of precision parts and decorative items, mainly sheets and foils. Such products include:

- color television shadow masks
- integrated circuit lead frames
- surface mount paste screens
- heat ladders, plates and sinks
- optical attenuators, choppers and encoder disks
- grills, grids, sieves and meshes
- washers, shims and gaskets
- jewellery
- decorative ornaments
- signs, plaques and nameplates
- Manufacture of burr-free intricate thin stampings



g. 2 Integrally stiffened engine fan and exhaust ducts

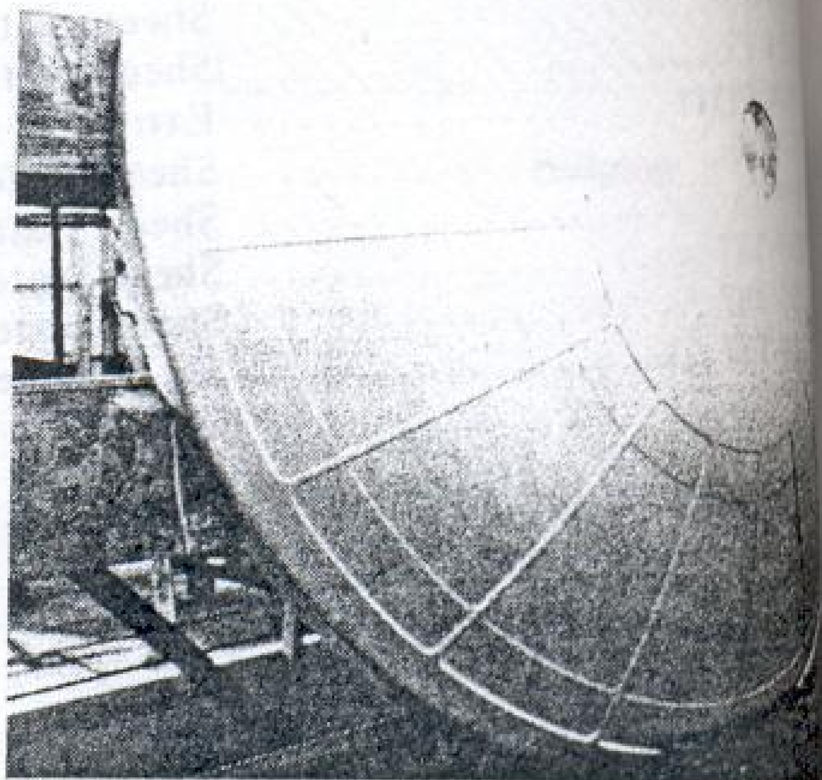


Fig. 11 Delta booster tank bulkhead

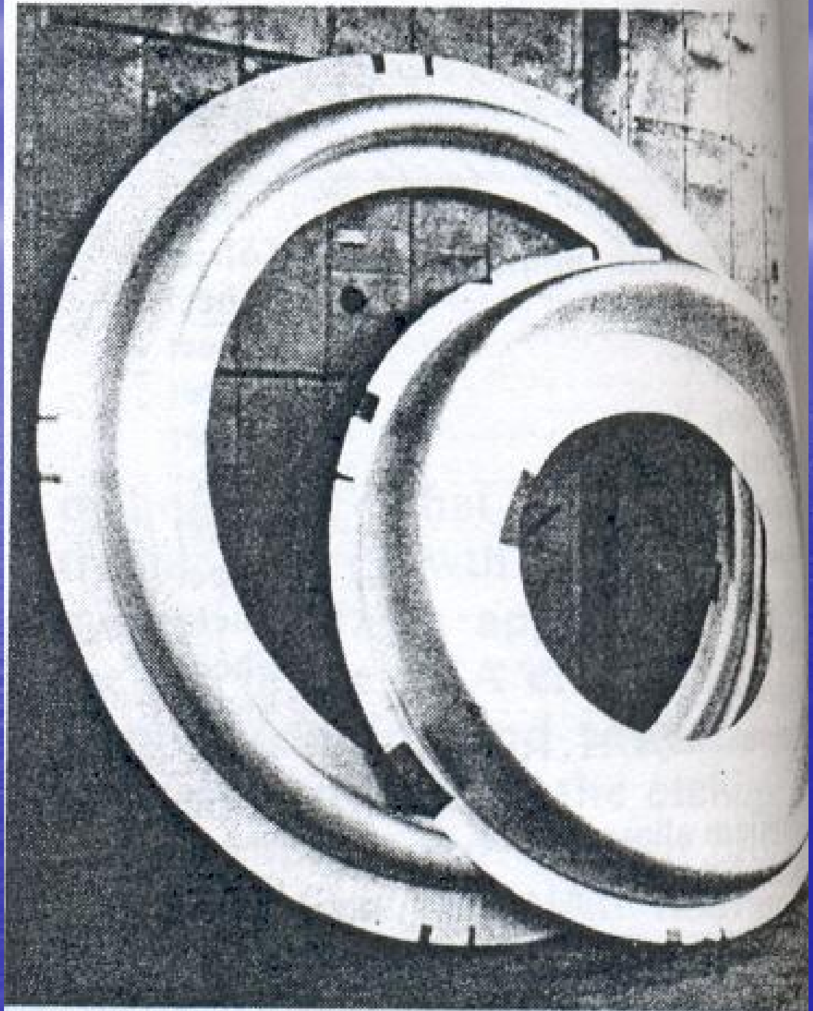


Fig. 12 Engine cowl inlet duct skins

Fig. 13 Engine cowl access door

Fig. 14 Titanium casting for combustor case

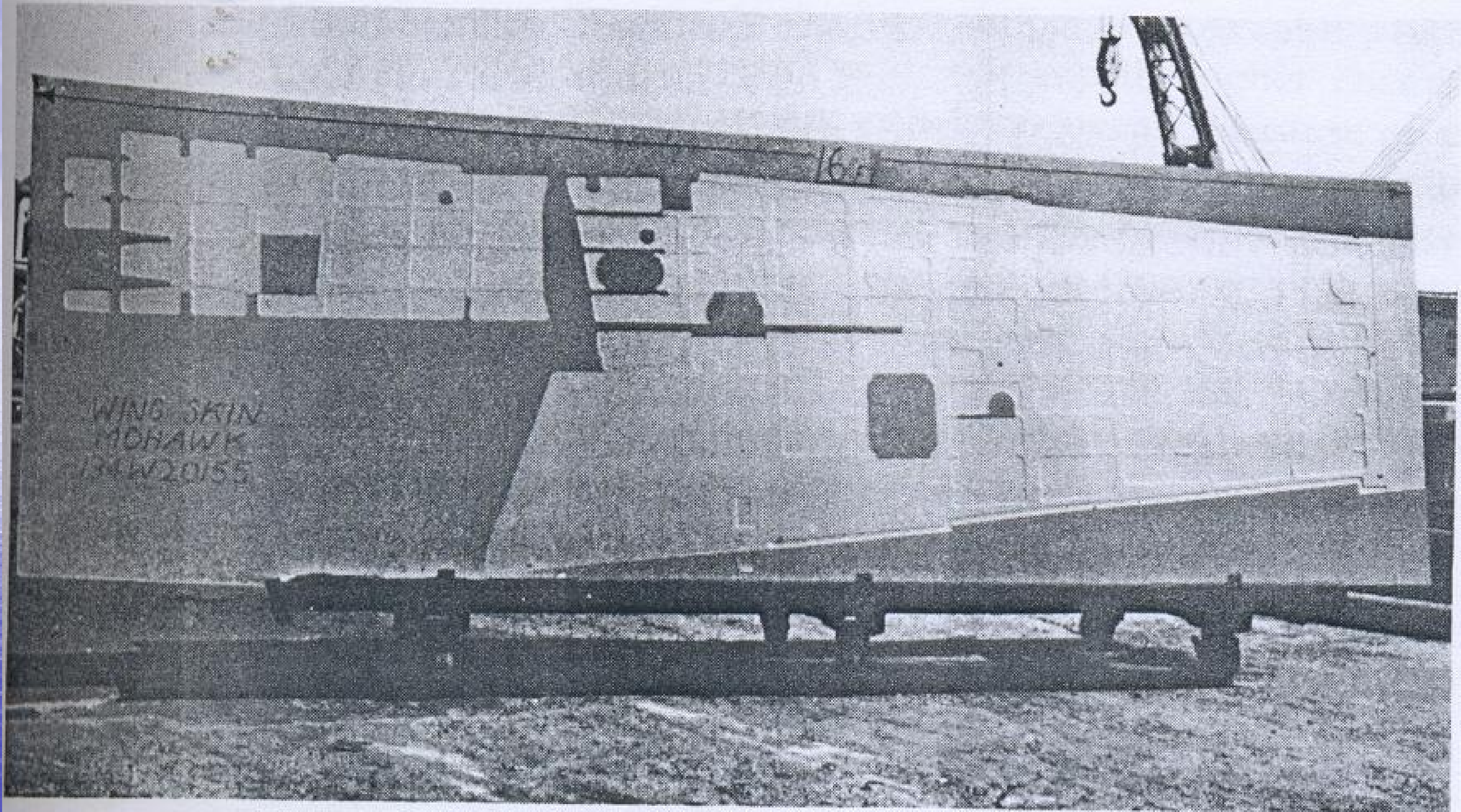


Fig. 4-1. Aluminum aircraft wing skin with numerous surface areas etched to remove unnecessary metal for better strength-to-weight ratio. *(Courtesy, Grumman Aircraft Engineering Corporation)*

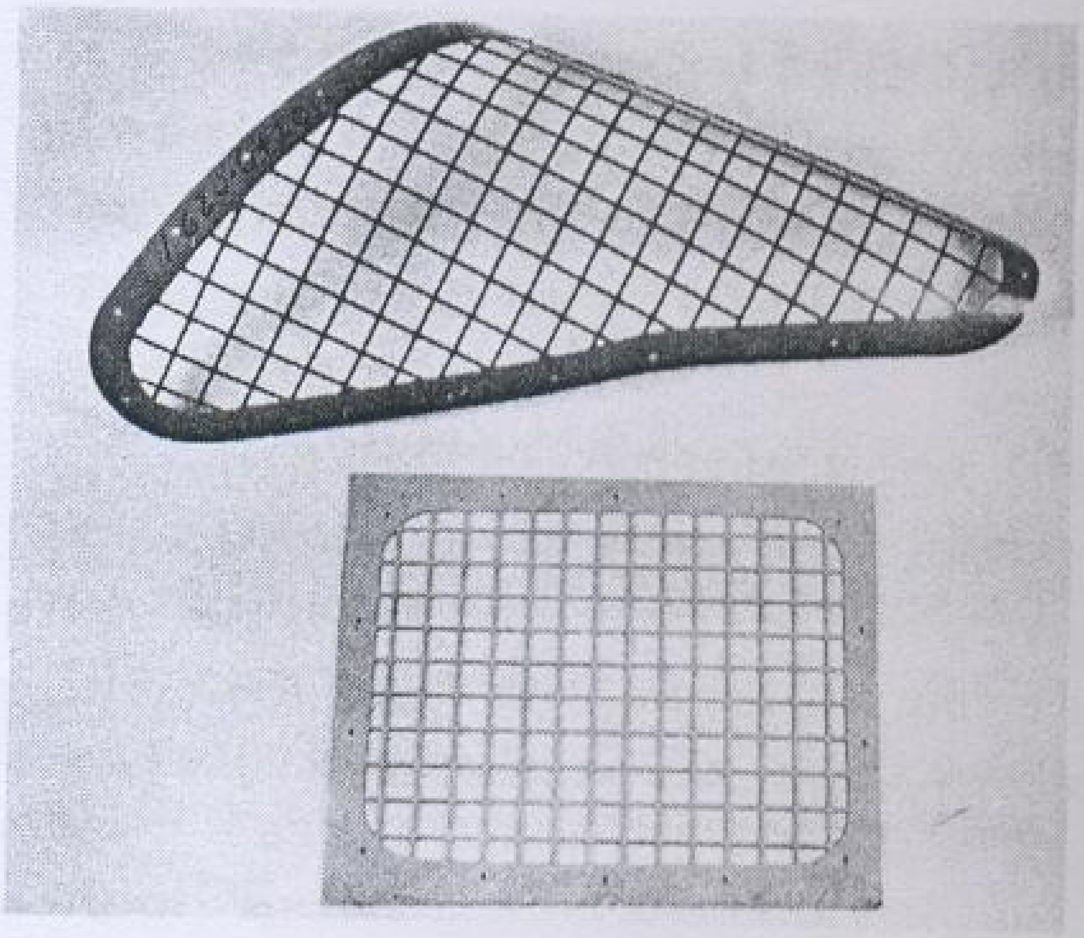


Fig. 4–2. Aluminum helicopter vent screens. *(Courtesy, Chemcut Corporation)*

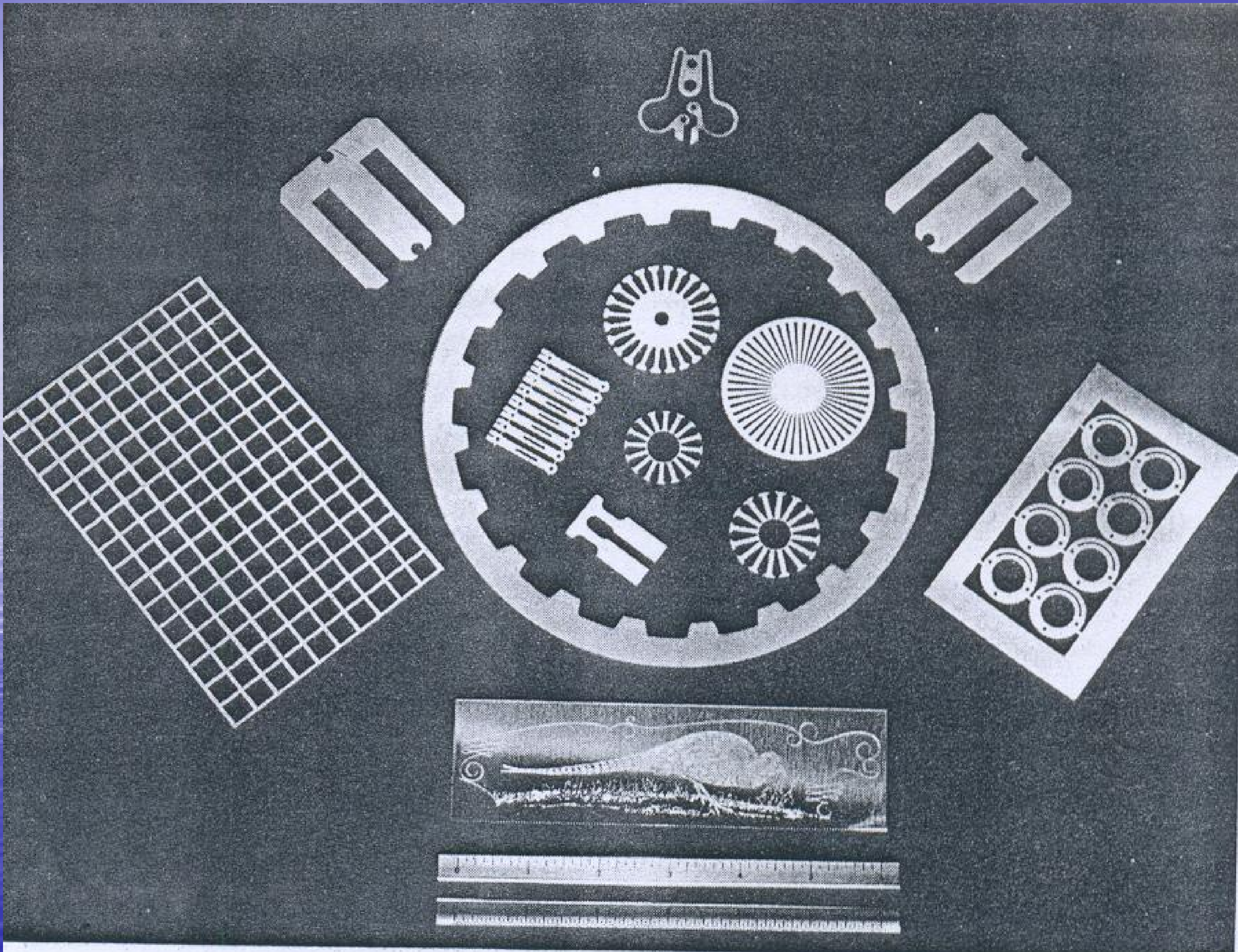


Fig. 4–27. Parts produced by chemical blanking. *(Courtesy, Chemcut Corporation)*

Parts produced by PCM