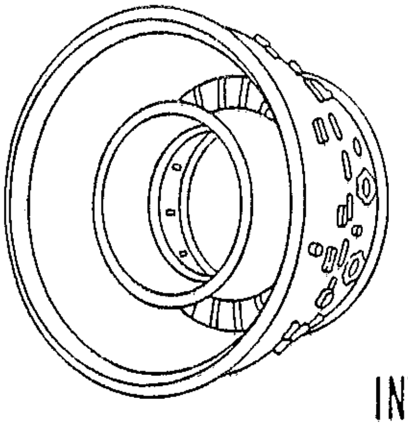
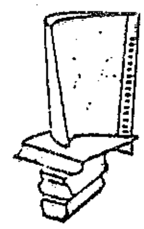


Diffuser Case



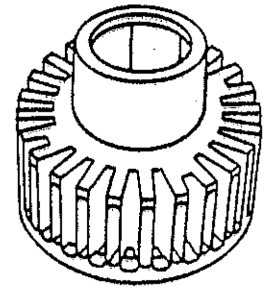
1st Stage HP Turbine Blade

INVESTMENT CASTINGS:

A NATIONAL SECURITY ASSESSMENT

U.S. DEPARTMENT OF COMMERCE
INTERNATIONAL TRADE ADMINISTRATION
OFFICE OF INDUSTRIAL RESOURCE ADMINISTRATION
STRATEGIC ANALYSIS DIVISION

DECEMBER 1987



Oil Separator

Investment Castings:
A National Security Assessment

Prepared by

U.S. Department of Commerce
Bureau of Export Administration
Office of Strategic Industries and Economic Security
Strategic Analysis Division

December 1987

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Investment Castings: A National Security Assessment - A national security/industrial capabilities assessment of the domestic investment casting industry. The report includes a detailed review of the investment casting industry and its performance, production capabilities, surge and mobilization capabilities, supply relationships, and a technology assessment. The report finds that U.S. firms lead the world in investment casting technology. This technological lead has a positive qualitative impact on defense capabilities, and has conferred competitive advantages on U.S. investment casting firms in the world aerospace market. The report notes, however, that the U.S. has a limited production base for some highly sophisticated investment castings such as hollow-core blades. Furthermore, the investment casting industry is dependent on foreign suppliers for materials, such as numerous metals, wax and wax blending materials, and selected ceramic shell making additives. The report concludes that as a result, lead times may rise to unacceptable levels in an emergency. The report closes with recommendations for Department of Defense consideration.

INVESTMENT CASTINGS:

A NATIONAL SECURITY ASSESSMENT

U.S. DEPARTMENT OF COMMERCE
INTERNATIONAL TRADE ADMINISTRATION
OFFICE OF INDUSTRIAL RESOURCE ADMINISTRATION
STRATEGIC ANALYSIS DIVISION

DECEMBER 1987

On The Cover

Diffuser Case - This casting is used in the Pratt and Whitney PW4000 gas turbine engine and requires a pour weight of over 1,000 pounds of superalloy. More than 80 wax shapes are assembled to form its 40" - diameter wax pattern. The PW4000 engine is used on the Boeing 747 and 767, the Airbus A300 and A310 and the McDonnell Douglas MD-11.
1st Stage HP Turbine Blade - This is a single crystal superalloy casting used in GE's F110 fighter engine. The F110 engine is used on the F-15 and F-16 fighter aircrafts.
Oil Separator - This casting exemplifies the complexity the investment casting process can achieve. Cast from aluminum alloy, the oil separator is used in GE/Snecma's CFM 56 engine. The CFM 56 is currently the world's best selling large commercial jet engine, used on the Boeing 737, Airbus A320, the AWACs and several other aircraft.

Cover illustrations provided courtesy of Howmet Corporation.

Investment Castings

Preface

Preface

This report was prepared by the U.S. Department of Commerce, International Trade Administration, Office of Industrial Resource Administration, Strategic Analysis Division. The principle members of the study team were:

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The information in this report was compiled from responses to an industry survey, supplemented by a review of available literature and numerous contacts with knowledgable public and private individuals. Comments or questions about the content of this report, or additional copies may be obtained from the Office of Industrial Resource Administration by telephoning (202) 377-3795, or by writing to:

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Overview

In the last twenty years the investment casting industry has emerged as a critical supplier to the defense and aerospace industries. Defense currently claims over 40 percent of total industry shipments. Defense has also accounted for close to 60 percent of blade and vane and aluminum investment castings consumption in recent years. Sales of investment castings have more than doubled in real terms since the mid-1970s to almost $1.6 billion in 1985. Sales are expected to grow from 5-7 percent a year for the next several years with continued growth centered in the aerospace market. Expansion should also continue into various industrial markets, such as those now served by forgings, stampings and other castings. The rate of expansion into new industrial markets, however will depend largely on further cost reduction refinements to the investment casting production process, which will make the investment cast product more competitive, and greater efforts on the part of individual investment casting firms to make potential end-users aware of the product's possibilities.

I. INTRODUCTION

Background

The Department of Commerce, International Trade Administration, Office of Industrial Resource Administration and the Department of the Army, U.S. Army Materiel Command and the U.S. Army Industrial Base Engineering Activity formed an assessment team to evaluate the defense peacetime, surge and mobilization production capabilities of the domestic investment casting industry. Based on the efforts of the assessment team, the Department of the Army released a report in April 1987, analyzing the ability of the investment casting industry to meet the requirements of the Armed Services.

The Department of Commerce, Office of Industrial Resource Administration (OIRA) has further refined the Department of the Army reporting effort into a national security/industrial capabilities assessment of the domestic industry. This assessment includes a detailed review of the investment casting industry and its performance, production capabilities, surge and mobilization capabilities, supply relationships, and a technology assessment. Appendixes are included at the end of the report detailing the investment casting process, strategic materials, a review of competing production processes, and selected statistics and graphs.

This assessment was completed by the Department of Commerce under authority of the Defense Production Act of 1950, as amended. Executive Order 11490 empowers the Department to analyze problems that may arise in maintaining an adequate mobilization production base in military related products and to take necessary actions to overcome these problems. Section 705 of the Defense Production Act authorizes Commerce to mandatorily collect information deemed necessary for this national security assessment. As part of the effort the Commerce Department, OIRA developed and disseminated an industry survey (See Appendix D), the data of which provided the basis for this assessment.

The assessment was initiated due to the critical position the industry occupies within the U.S. defense industrial base. The Department of Defense Industrial Preparedness Manual (DOD 4005.3M) identifies "precision castings" as a known critical subcontractor product which should receive particular planning attention.

In addition, several recent studies have identified investment castings as long lead time items which could constrain the availability of critical weapons systems in the event of a surge or mobilization emergency. These studies, all of which recommended more detailed analysis of the casting industry, include:

a. The FY-84 United States Air Force Production Base Analysis, a joint Air Force/Industry Assessment of the Aerospace Industrial Base. This study, which includes the "Blueprint for Tomorrow", identified precision (investment) castings as a long lead buy item and a production constraint during peacetime, surge and mobilization scenarios.

b. The Analytic Science Corporation study of the Investment Casting industry completed for FEMA in 1984. This study indicated investment castings in aerospace applications could have lead times of up to 18 months because of constraints in tooling, test equipment, conversion to defense production, capacity expansion and critical personnel.

c. The 1985 Hughes Aircraft Corporation study of the Bradley Fighting Vehicle. This study highlighted certain critical castings for the system as having lead times as long as 42 weeks.

Despite these studies, and the growing strategic importance of investment castings to the military capabilities of the United States, there was a lack of information on this industry's defense production capabilities, particularly at the plant level. The inadequate attention focused on this industry was due in part to its structure in the procurement hierarchy. The industry is primarily composed of second and third tier subcontractors, which are, compared to prime contractors, inherently more difficult to isolate and analyze. The following attempts to fill this information void.

II. INDUSTRY DESCRIPTION

Investment Casting

The investment casting process has been variously termed the "lost-wax process", "precision casting process", and the "precison investment casting process". The first stage in the process is the construction of a metal die fitting the precise dimensions of the part desired. Wax is then injected into this die to produce a pattern of the part. The wax pattern is next coated (or invested) with a ceramic slurry solution to create an investment shell around the pattern. After the shell has dried and hardened the shell/pattern monolith is inverted and placed in an autoclave to melt out the wax. When the shell has been cured and any remnants of wax burnt out, there remains a ceramic mold with the exact dimensions of the desired part. Molten metal is then introduced into the mold to cast the part.

After cooling the shell is removed from the part in a stage referred to as "knock-out". Where necessary, gates and runners (channels formed in the mold to allow metal to flow into the mold cavity) may have to be removed from the casting and surfaces finished. Normally, after a series of non-destructive testing procedures to ensure the quality and accuracy of the casting, no further work is needed. In some cases it may be necessary to conduct minor machining, welding, or grinding. Depending on applications, the part may be strengthened by heat treating. (A detailed description of the investment casting process is found in Appendix A.)

Industry History

Many modern industrial applications of the investment casting process are considered high technology. However, the basic technique of using an expendable pattern in a ceramic mold has been traced at least as far back as 4,000 B.C. Since that time, the process has been handed down in a variety of cultures throughout the world as a means of producing ornamental and functional metal objects.

Modern investment casting received its initial impetus at around the turn of the century when the need for precise dental fillings, crowns, bridges, etc. led to improvements in casting techniques. Interest in the process spawned over 4,000 separate patents relating to investment casting in the forty years between 1900 and 1940, with the bulk of this research and development remaining in the narrower field of medical applications.

The first significant industrial applications of the process emerged in the late 1930's, during the period in which it was discovered that cobalt based alloys possess highly desirable properties at high temperatures. Parts produced up to that time from conventional alloys for use in heat engines were not suited to the elevated temperatures at which the new generation of engines were being designed to operate. Although an attempt was made to integrate the newly developed "superalloys" into these designs, conventional machining of these metals to a high degree of accuracy proved to be extremely difficult, and it was quickly realized that investment casting provided a superior process.

The potential for applications of investment casting for industrial engineering expanded greatly after World War II with the development of gas turbine and jet engines. Gas turbine engines require precisely calibrated parts cast from temperature resistant metals, and for these purposes hollow investment cast turbine blades and vanes soon became a standard product. Most early investment casting firms were closely tied to the outlets they found in aircraft companies and government establishments pioneering in the new technologies. As the commercial and military markets for these engines expanded in the 1960's and 70's, the investment casting industry grew accordingly.

The close links between prominent investment casting firms and major manufacturers in aerospace products and power generating equipment (e.g., General Electric, Pratt & Whitney, and Boeing in the United States and Rolls Royce in the United Kingdom) that were developed in this period have continued. Although it is not known with certainty what percentage of total sales is actually accounted for by these large end users, it is clear that the figure is large and that the technological demands placed on investment casters by these high technology end users are a prime influence on the industry.

Three firms (Howmet, Precision Castparts, and Arwood) have emerged as the lead suppliers to the gas turbine engine market during the last twenty years, and a large share of advanced research and development in materials, processes, and design is currently conducted at facilities operated by them, along with a handful of medium sized producers in this segment of the market. Through their foreign subsidiaries and international marketing links, these firms have also developed and expanded the international market for precision investment castings used in GTE's. The remaining medium to small U.S. firms are primarily involved in applying existing casting technology to a rapidly expanding range of industrial and consumer products. The development of other non-GTE related markets has lessened the image associated with investment casting as the "exotic and expensive" segment of the metal parts industry, and loosened the ties between sales in the industry and a small number of large aerospace corporations.

Current Industry Profile

In 1985, an estimated 160 firms produced investment castings in 182 facilities in the United States. The establishments are widely distributed across 32 states. The leading four states (Oregon, Michigan, New Hampshire and California) account for 44 percent of the industry's employment. The next four states (New Jersey, Ohio, Indiana and Texas) account for an additional 28 percent. California has the most investment casting plants with 20, followed by Ohio and Pennsylvania which each have ten.

The average number of employees per facility is 130, ranging from only a few people to almost 2,000 for individual establishments. Slightly less than half (45.6 percent) of the total number of plants have 50 or fewer employees, but these only account for 9.7 percent of total industry employment. Also, many of these smaller plants are engaged solely in art, jewelry, or bone "implant" investment casting, and as such were of only marginal interest to this assessment. In contrast, only 11 plants have more than 500 employees, but they account for 45 percent of industry employment.

The distribution of establishments by employment size is as follows:

Employment Range	Establishments	Total Employment
50 and fewer	83	2,283
51 - 149	66	5,478
150 - 499	22	5,212
Over 500	11	10,631
Total	182	23,604

Source: DOC/OIRA Industry Survey

Investment casting plants tend to specialize by size and weight of casting, sophistication, and to an extent, materials cast. For analytical purposes, we segmented the industry into several subsectors along lines of plant specialization. The most defense critical of these are "blade and vane" investment casters, who also rank as the most sophisticated. Blades and vanes are fin like structures attached perpendicularly to gas turbine engine shafts. Set at an angle to the direction of thrust, the blades are deflected by exploding gases forcing the shaft to turn. Aluminum is a material that requires specialized equipment to investment cast, and therefore has developed as another specialized subsector. The military/aerospace markets are also the major users of aluminum investment castings.

Other specialization tendencies include ferrous investment casters (that can be further delineated into several size/weight categories); art and jewelry foundries; and, pushing at the edge of the technology, titanium and ultra large investment castings. The blade and vane and aluminum subsectors are broken out separately in Part IV - Production Capabilities, and Part V - Surge and Mobilization Capabilities since each is a major defense supplier.

The structure of the investment casting industry is quite concentrated in terms of company sales. The top five companies accounted for 61.5 percent of total industry sales in 1985. Four of these top five companies are also the major blade and vane producers, accounting for about 85 percent of total blade and vane sales. The next five firms in terms of sales accounted for another 8.5 percent and the five after that, an additional 4.2 percent. Thus, the top fifteen concerns accounted for 74.2 percent of total industry shipments.

The table below further delineates this concentration by placing the companies into three categories of sales volume. As shown, 17 firms reported 1985 sales exceeding $10 million. The sales of these firms constituted 75 percent of total investment casting shipments. The 90 firms with sales of less than $2.5 million represented only 5.2 percent of total shipments. Most of these low sales volume firms have fewer than 50 employees.

Sales Volume	Number of Companies	Number of Plants	1985 Shipments (in $millions)
over $10 million	17	37	$1,164
$2.5 to $10 million	53 (e)	55 (e)	307 (e)
Under $2.5 million	90 (e)	90 (e)	81 (e)
Total	160	182	$1,552

(e)-estimate

Source: DOC/OIRA Industry Survey

Firms with less than 50 employees averaged just over $49 thousand in shipments per employee. Larger firms averaged about $67.4 thousand per employee, or about 37 percent more than the smaller firms. Relative to small firms, larger firms tend to be more capital intensive, more sophisticated and operate with more shifts, all of which serve to increase their shipments per employee.

In contrast, shipments per employee for all manufacturing is almost twice that of investment castings at $130.2 thousand (1985 data). The relatively low shipment value of employees in the investment casting industry compared with all manufacturing reflects the labor intensity of the investment casting process. Investment casting is generally low volume, complicated work that is difficult to automate. Frequent changes in production runs and delicate mounting of a variety of wax patterns into carefully planned configurations requires extensive human intervention.

Markets

Investment castings are currently used in a variety of military and non-military applications. In value terms, the market for military and commercial gas turbine engine investment castings by far dominates industry sales. However, other markets including valves and pumps, oil and chemical processing equipment, and various other machinery and equipment related applications are also significant. In the following discussion markets for investment castings are divided into: 1) the military/aerospace market, and 2) the commercial market.

Military/Aerospace Market

The table below summarizes U.S. defense purchases of investment castings between 1983 and 1985. Turbine blades and vanes dominate these purchases in terms of value with almost 57 percent of the total. These blades and vanes are primarily for gas turbines used in airborne applications, although a growing number of ground and marine applications also apply. Other aerospace end uses, which include missiles, airframes, a substantial portion of the electronics, and other systems, accounted for an additional 30 percent of purchases for a combined aerospace related share estimated at nearly 85 percent. Of these military shipments it was estimated by the Department of the Army that about 61 percent went to the Air Force, 19 percent to the Navy, and 17 percent to the Army.

Military/Aerospace Quality Investment Castings

Defense Purchases, 1983-1985

Product Area	Value ($ millions)	Percentage
Turbine Blades and Vanes	$840,469,000	56.7%
Turbine, Other	131,481,000	8.9%
Missiles	115,302,000	7.8%
Aircraft-Airframes	67,819,000	4.6%
Aircraft, Other	66,985,000	4.5%
Tanks	65,462,000	4.4%
Electronics	64,139,000	4.3%
Weapons	18,213,000	1.2%
Automotive	536,000	--
Other	112,190,000	7.6%
TOTAL	$1,482,596,000	100.0%

Source: DOC/OIRA Industry Survey.

The aerospace and military markets for investment castings are distinguished by a high level of precision and the use of special alloys. As a result, this segment of the market represents the high value sector of the industry, and embodies the most sophisticated process technologies. Aircraft and gas turbine engine end uses are the biggest single markets for investment castings overall, and firms within the aerospace sector have typically developed supply relationships with large end users such as General Electric and Pratt & Whitney. Close to 50 percent of the sales by Howmet and PCC, the two giants in aerospace castings, go to Pratt & Whitney and General Electric alone.

Demand for lighter, faster, and more fuel efficient aircraft for military uses has greatly stimulated demand in this market, and investment casting has emerged as a key process at the forefront of developments in aircraft technology. Thus, although the concentration to date has been primarily on smaller engine components such as turbine blades and vanes, the market now appears to be shifting toward the production of large structural components.

Developments are also occuring in applying new materials for advanced aircraft castings. Titanium structural components, for example are produced on a regular basis. Titanium is also being used in conjunction with composite airframes since it is one of the only metals that does not corrode on contact with composites. Further, applications involving aluminum based alloys are now being adapted for hot sections of gas turbine engines.

Commercial Markets

Commercial markets include a broad range of mostly steel parts used in machinery, components such as valves and pipe parts, and specialty equipment such as medical instruments and golf club heads. In nearly every case, a commercial investment casting is designed for a specific piece of machinery and cannot be used in any other application. It is consequently impossible to speak of a "standard" commercial investment casting per se.

Commercial Markets For Investment Castings

Machinery Parts	Components
Heat Engines	Valves
Air Compressors and Pumps	Piping
Electronics and Computers	
Food Processing	Specialty Applications:
Materials Processing	
Hardware	Medical Instruments
Machine Tools	Precision Instruments
	Jewelry and Art

Source: DOC/OIRA Industry Survey

Oddly shaped valves, piping, and other parts used in chemical processing are a major commercial market. Parts for air compressors and pumps, machinery used in food and materials processing, and those for electronics, computers, and hardware, also fit into this category as do medical, navigation, and other precision instruments.

Growth in commercial markets for investment castings is in large measure dependent upon how widespread knowledge of the design and cost advantages of the process becomes within the manufacturing community. A recent study conducted by the American Foundrymen's Society concluded that over two-thirds of current casting users have been using investment castings for more than ten years. One consequence of this is that future growth in demand for commercial castings is likely to come from existing customers.

Production Cost Analysis

The following analysis draws heavily from DOC/Bureau of the Census statistical publications on the Steel Investment Casting Industry (SIC 3324). The data excludes certain nonferrous foundries which could affect the aggregate numbers, although we believe this to be only a minor problem. A greater concern is that the aggregate numbers conceal large variations in relative costs between individual investment casting plants. Production costs will vary significantly with plant specialization according to the size, weight, material, shape, and specifications of the casting in question. Aggregate Census figures for the investment casting industry, while reflecting overall industry averages, do not relate costs on the basis of these important distinctions. Consequently, the material that follows should be used only as a rough indicator of comparative costs and relationships between broad industry categories.

Labor Costs

In investment casting, labor is engaged in wax injection, pattern assembly, investment coating, casting, inspection, finishing and assorted support activities. Total labor costs include wages and salaries, employer social security contributions and other social payments such as medical insurance. The total labor bill in 1985 for steel investment casters was reported by the Bureau of the Census at $500.3 million. Of this amount, payroll came to $394.9

million and social payments to $105.4 million or just over 20 percent of the total. Total labor payments constituted 62.7 percent of the value added by the steel investment casting industry. (Value added is defined as the difference between the total dollar sales and the cost of materials, adjusted for changes in inventory levels.)

The average wage paid the steel investment casting production worker has been between 20 and 25 percent less than production workers receive in other ferrous foundries, and about seven percent below that of the manufacturing sector as a whole.

Several factors are believed to account for these differences:

1. The investment casting process is labor intensive, which reduces the productivity of the marginal hiree below that of more capital intensive industries, such as other ferrous foundries. The wax pattern making/assembly process is particularly labor intensive and may account for as much as 40 percent (or more) of total employment in some foundries. As this is a semi-skilled operation, workers have been fairly abundant relative to demand and have not commanded high wage rates. Their low wage rates coupled with their large numbers can have a considerable downward pull on overall average wage rates.

2. The wax pattern making and assembly operation is intricate and time consuming. Female workers have demonstrated a superior physical and psychological capability for delicate work of this nature as evidenced by their occupying most of these positions. Female employees tend to be paid less than their male counterparts.

3. Investment castings sales tripled in the last ten years which has resulted in the hiring of substantial numbers of new employees. If a correlation between employment tenure and income can be drawn, a growing industry would be expected to have lower average employee tenure and lower average wages than a mature or declining industry. Interestingly, employment in other ferrous foundries fell by almost 40 percent between 1981 and 1985.

4. Various environmental and workplace safety laws in the last twenty years have driven ferrous foundries to enlarge the scale of and automate their facilities. This trend enabled many foundries to better absorb the costs of the special equipment required to comply with the laws. The end result was a substantial increase in the productivity of the work force. Investment casters were not able to automate their operations to the same extent as other ferrous foundries and thus they did not experience the same growth in productivity. This divergence has enabled the other foundries to pay higher marginal labor rates.

The average wage level in investment castings grew by 29.3 percent between 1981 and 1985. In contrast, wage levels in all manufacturing grew 22.9, and in other ferrous foundries by 24.5 percent.

Average Hourly Wage For Production Workers

	All Manufact-uring	Steel Investment Casting	Other Ferrous Foundries
1981	$8.09	$7.13	$ 9.58
1982	8.70	8.08	10.38
1983	9.00	8.60	10.92
1984	9.41	8.75	11.49
1985	9.94	9.22	11.93

Source: DOC/Bureau of the Census

Material Costs

Material costs embody the casting alloy, shell materials (both refractories containing trace elements and binder), wax pattern materials, various testing chemicals and energy purchases. The table that follows gives a rough indication of the total cost of these materials relative to shipments value.

Cost of Materials (% of Shipments Value)

	All Manufacturing	Steel Investment Castings	Other Ferrous Foundries
1981	59.2%	37.3%	47.8%
1982	57.7	35.5	43.9
1983	57.0	37.8	45.5
1984	57.2	37.5	43.5
1985	56.0	37.8	44.2

Source: DOC/Bureau of the Census

The low percentage shown for investment casting material costs is a reflection of the higher value that is added in the investment casting production process. This can also be explained by the additional equipment downtime numerous product changes (i.e., many small production runs) place on the investment caster. The foundry must, in this circumstance, reset machinery and change operating parameters at frequent intervals, driving "equipment" productivity far below its potential. However, while the greater "downtime" of the machinery is unproductive, costs continue accumulating and must be recovered in higher selling prices, which drives the value added up for each casting.

Material costs vary proportionally with casting size and production volumes. Metal costs reportedly range about half of total material costs, or between 15 and 20 percent of shipment values. Of course, much also depends on the metal, the sophistication of the plant, and the tolerances and complexity of the casting. Energy costs totalled $50.3 million in 1985 (about 4 percent of shipment values), of which electrical energy purchases were about two-thirds.

Wax pattern materials are not a major direct cost in the production process, and to some extent expenses are kept down by recycling activities. Most investment casting foundries have a system of wax recovery built into the burn-out furnaces, and the recovered wax is then processed for re-use. Mold materials, on the other hand, are not recoverable and consequently must be carried in larger volumes (and cost) in plant inventories. Indications are that the current levels of inventories, and associated carrying costs, are above normal because of periodic shortages of critical mold materials, such as zirconia.

Between 1981 and 1985 prices of materials have remained stable, and in some instances fell. The table below shows price trends for selected metals that are used extensively in investment castings:

Selected Metals Price Trends, 1981-1985
($/lb)

	Cobalt	Nickel	Titanium	Aluminum	Steel
1981	14.58	2.65	7.65	0.76	0.24
1982	8.56	2.24	5.55	0.76	0.25
1983	5.76	2.20	5.55	0.78	0.26
1984	10.40	2.22	5.55	0.81	0.27
1985	11.50	2.28	5.55	0.81	0.28

Source: Bureau of Mines

Overhead Costs

Plant and equipment costs such as principal and interest on loans, property taxes, utilities and rent are fixed and must be spread over the output of the firm. Overhead costs typically will vary greatly from plant to plant because of differences in their market orientation, sophistication and capital intensity. For example, in casting superalloys, most foundries use vacuum furnaces which are considerably more expensive than air furnaces. As another example, large castings require heavy materials handling equipment which is also expensive.

What might be termed a "semi-variable" cost associated with investment casting is the design and fabrication of the die. Unlike general overhead costs, the die cost is spread over the total production of a specific casting. In some instances the die can have a useful life extending for many years over which its cost must be carried and ultimately recovered. Individual dies cost as little as a few hundred dollars for simple parts, to more than $250,000 for a large structural component. These costs will depend on the complexity, size, and dimensional tolerances of the die.

In constructing an investment casting plant, it may not pay the firm to incur the overhead costs of a fully tooled machine shop. It is often cheaper to subcontract the initial die fabrication for a fixed fee, since the need for new dies is uneven and hard to predict. Many firms maintain a machine shop to make some of their own dies and for repair work.

<u>Cost Reduction Programs</u>

In an attempt to limit the costs associated with new product development, a number of firms are experimenting with CAD/CAM technologies. A particularly hopeful project concerns software which will allow engineers to simulate various "gating" configurations connected to metal castings without expensive prototypes. This could greatly reduce the time and cost of actual repeated trial runs. In another effort, software applications are being developed to enhance "just-in-time" inventory control. A computerized materials flow-through system has already been demonstrated by at least one investment casting firm. This system has accelerated throughput and reduced the incidence of bottleneck disruptions.

Research and development at the largest firms has been focused on new equipment and process modifications which speed the process and minimize material wastage, defects, and bottlenecks. However, the automation of the process is still in its early stages and does not characterize the industry as a whole.

To quicken the pace of advancements in R&D, some firms have introduced organizational changes. For example, a number of larger firms have begun consolidating R&D activities at a single location, while others (often of necessity) are pooling development activities and costs with purchasing firms. Hitchiner Manufacturing, for example, has a joint venture with General Motors to conduct applied R&D. On the shop floor at another firm, experiments are being conducted to establish production teams. These teams have concentrated on a similar family of parts which both speeds labor along the learning curve and reduces equipment set-up times.

III. INDUSTRY PERFORMANCE

Shipments

Shipments by the surveyed investment castings firms for the 1981 to 1985 period are presented below.

Shipments of Investment Castings
$000

	1981	1982	1983	1984	1985
Defense	$ 409,107	$ 420,239	$ 439,591	$ 591,206	$ 644,680
Non Defense	787,561	726,644	699,644	784,425	907,305
Total	$1,196,668	$1,146,883	$1,139,235	$1,375,631	$1,551,985
% Defense	34.2%	36.6%	38.6%	43.0%	41.5%

Source: DOC/OIRA Industry Survey

Shipments increased 30 percent since 1981 (13.3 percent in constant dollars), to a record level approaching $1.6 billion in 1985. The most recent years account for most of this growth (21% in 1984 and 13% in 1985 over the previous year's total), while 1982 and 1983 showed slight declines in shipment levels because of a slump in aerospace related sales and other casting markets.

This table also breaks down shipments of investment castings by defense and non-defense (commercial) usage. In the non-defense sector, shipments were more variable than the overall total, declining 8 percent in 1982 from 1981 levels, and another 4 percent in 1983 before showing strong growth in 1984 and 1985 (12.1% and 15.7%, respectively) in response to an expanding commercial large aircraft market and overall economic recovery.

Defense shipments, about 85 percent for aerospace applications, have shown consistent growth over the 1981 to 1985 period. Investment casting sales to defense uses rose from $409 million in 1981 to $645 million in 1985, a 58 percent increase (37.8 percent in constant dollars) in five years. Moreover, defense-use investment castings have accounted for an increasing share of total shipments, reaching over 40 percent of sales in recent years.

The largest firms (those with over $10 million in sales annually) account for about 80 percent of defense shipments, and about 70 percent of commercial shipments. Medium size firms ($2.5-10 million in sales) account for an additional 16 percent of defense and 22 percent of non-defense shipments. The smallest firms, those with less than $2.5 million in sales, account for the remaining shipments.

The future for investment castings shipments is fairly bright, although military shipments appear to be stabilizing. However, the commercial aircraft industry is expected to experience continued growth over the next several years as air carriers modernize and expand their fleets. Furthermore, the demand for investment castings may increase as jet engine and turbine designers are increasingly confronted with demands for lighter weight, more heat resistent, and lower cost products. Investment castings made from superalloys and other materials can meet these stringent requirements.

There is also potential for the increased use of investment castings in other industries, such as in turbochargers for automobiles. A number of industry specialists believe that education and publicity about the virtues of investment castings may help boost sales to new uses in the future. With these considerations in mind, it is estimated that the growth rate of shipments will be in the range of 5-7 percent per year over the next several years.

Employment

Employment trends in the investment casting industry were calculated from survey data, and are presented below.

	Production Workers	% Change Over Prev. Year	Total Employees	% Change Over Prev. Year
1981	14,699	--	18,211	--
1982	13,979	-4.9%	17,439	-4.2%
1983	13,563	-3.0%	17,162	-1.6%
1984	16,506	+21.7%	20,625	+20.2%
1985	18,892	+14.5%	23,604	+14.4%

Source: DOC/OIRA Industry Survey

Employment in the industry closely tracks the trend observed in shipments of investment castings. Like shipments, employment declined in 1982 and 1983 due to declines in aerospace and other casting markets. Employment in 1984 and 1985 showed a sharp increase, surpassing previous high levels and demonstrating that the industry's growth continues to exceed that of the general economy.

The table also indicates that investment casting production workers (e.g., pattern assemblers, wax injectors, testing personnel, etc.) account for the bulk of employees in the industry, at around 80 percent. The remaining occupations include supervisors, engineers and scientists, and administrative staff. As expected, production worker employment levels are slightly more volatile in response to economic cycles than those for non-production workers.

Future employment in the investment casting industry will likely increase as aircraft producers are expected to increase their demands, as other markets develop and as investment casters find ways to further reduce the cost and increase the quality of investment castings.

Investment

Investment information was collected from investment casting firms with 50 or more employees. Their aggregated responses are shown below.

Investment in Plant and Equipment

$Millions

	1981	1982	1983	1984	1985
Plant	$ 7.3	$ 4.6	$27.0	$ 7.5	$10.8
Machinery	29.2	26.5	43.8	34.9	45.9
Total	$36.5	$31.1	$70.8	$42.4	$56.7

Source: DOC/OIRA Industry Survey

Investment has been rather variable over the 1981-1985 period. As expected, most (between 80 and 85 percent) of investment dollars went to new machinery and equipment, with plant expansion accounting for the remainder. In 1983, investment in plant was particularly high, at $27 million, largely because three firms underwent major expansions in that year. The remaining four years show investment levels in the $30 to $40 million range. 1985 levels are slightly higher, at $56.7 million, and may indicate a new trend in investment.

Although equipment-specific investment information was not collected, it is possible to hypothesize that the investment castings firms invested considerable funds into modernizing their facilities, based on their responses to other survey questions. Specific equipment would include robotics for use in the shell formation process, CAD/CAM systems, real time imaging machines for the inspection process, and other automated equipment for reducing the labor requirments of the grinding, finishing, and inspection operations.

Capital investment per production worker was calculated from the survey responses so comparisons with other industries could be made. The table below presents such information for some related industries as well as for the manufacturing sector as a whole.

Capital Investment Per
Production Worker

	1981	1982	1983	1984	1985
Investment Castings	$2483	$2225	$5230	$2569	$3001
*Steel Inv. Cast	1706	2611	1903	1866	3645
*Ferrous Foundries	5492	3894	2719	3212	4096
*Nonferrous Found.	3263	2837	2632	4625	3850
*Forgings & Stampings	6230	5144	3060	4264	6050
*All Manufacturing	5860	6013	5101	5976	6839

Source: DOC/OIRA Industry Survey and Bureau of the Census(*)

From these figures, it can be seen that the Commerce survey data closely tracks the Census data for steel investment castings, although survey data also includes products made of aluminum, titanium, and other nonferrous metals. 1983 is an anomaly, when investment rose greatly among the DOC-surveyed firms in the nonferrous sector. Also, investment per worker is lower in the investment castings industry (both sources of information) than in the other sectors shown. This lower per worker investment is a further indication of the labor intensity of investment casting.

The investment castings firms were also asked whether they were planning any expansion or contraction of operations. The respondents foresaw the following:

% Expansion/Contraction	% of Respondents
< 0% (Contraction)	1.6%
0% (No change)	31.7%
+1%-24%	12.2%
+25%-49%	11.4%
+50%-99%	18.7%
Over 100%	24.4%
	100.0%

Source: DOC/OIRA Industry Survey

As can be seen from the above figures, most firms were either planning no growth (31.7%), or were planning a rather large increase in capacity (more than 50% increase). Many of the firms planning an increase indicated that they were doing so because they were entering new markets, modernizing, or generally expanding their business. Furthermore, in general, the smaller firms (50 or fewer employees) tended to foresee more expansion: of them, 30 percent planned an expansion of 100 percent or more, versus 20 percent of the larger firms.

Among the largest firms, Howmet, Precision Castparts (PCC), and Arwood all have major expansion plans in the works. Howmet has planned a $16 million dollar expansion of its Virginia plant to produce larger aerospace components, and is in the process of opening a new plant in Tennessee to produce sophisticated patterns and subassemblies for use in the investment casting process. PCC, which recently merged with TRW, is planning to expand its capital stock to increase capacity for hot isostatic pressing (HIP'ing) and vacuum treating.

International Trade

Data on imports and exports of investment castings are not available from official U.S. statistics. Most of what is known is anecdotal, and on balance indicates the U.S. is a net exporter. An active replacement market exists for blades and vanes; and with a large portion of original gas turbine engines exported, we can surmise that both original and replacement blades and vanes for these engines are also exported. However, for industrial type investment castings, the reverse may be the case as several firms identified specific instances of lost sales to foreign competitors.

Investment cast hose couplings, gas caps, golf clubs, handguns, valves and pump components were named as frequently imported parts. U.S. investment casters appear to be vulnerable to lower cost foreign producers in these markets, especially from countries that have a substantial labor cost advantage. Imported castings are reportedly entering the United States from Israel, Spain, South Korea, Japan and Taiwan, and we suspect in steadily increasing quantities.

The bulk of investment castings traded into and out of the United States are "indirect" (i.e., they enter as components contained in various types of finished machinery). The most important and actively traded of these markets, from both a military and commercial standpoint, are the gas turbine engine markets. These engine markets account for approximately 70 percent of the total value of industry sales. In this light, the fortunes of U.S. foundries supplying gas turbine engine manufacturers are closely linked to the global performance of U.S. gas turbine engine firms.

The table below summarizes performance in the Aircraft Engines and Parts industry (SIC 3724) for the years 1982-1986. However, a good correlation cannot be drawn from these numbers because both imports and exports contain American manufactured investment castings. Also, it is next to impossible to estimate the content of castings in these numbers, because many castings are exported "directly" for use in foreign made, foreign used engines. Thus, the numbers should be used only as a very general indicator of trends.

Aircraft Engines and Parts
($ Thousands)

	1982	1983	1984	1985	1986
Shipments	11,641	11,516	12,641	14,251	15,228
Imports	1,319	1,130	1,605	2,331	3,036
Exports	2,539	2,736	2,984	3,282	3,495

Source: DOC/Bureau of the Census

Some of the largest aerospace investment casting firms have followec their major customers (such as General Electric) into the European market, and have established foreign production facilities. The United Kingdom, France, and other countries (as important aircraft engine manufacturers) have been major targets of this foreign direct investment and licensing activity. The top U.S. manufacturers of aerospace investment castings have a significant technological lead over foreign producers, which presently earns them a healthy economic rent in foreigr markets. However, as the technology diffuses to the European and Japanese foundry industries (as it already appears to be doing) this lead could diminish.

Major end products outside of the aerospace market such as automobiles, food processing equipment, specialized hydraulic equipment, and medical implants are also heavily traded, and there is no question their trade performance has an effect on investment casting sales. In many of these markets the U.S. trade position has diminished, or fallen into deficit in recent years which would indicate a general decline in the trade balance of industrial investment castings.

Foreign Relationships

Eleven U.S. investment casting companies reported a total of 30 existing foreign relationships with firms located in 14 different countries. These relationships included several types: licensing agreements, foreign owned subsidiaries, affiliates, sales agreements and one joint venture. The relationships are predominantly entered into by large firms, although several smaller firms also reported involvements. The types of relationships and their distribution by country are shown on the table that follows.

The 15 licensing agreements were reported by three large U.S. companies. This is indicative of the technological leadership of U.S. firms in this field. The immediate and short-term impacts of licensing agreements on the firms entering into them are beneficial in terms of licensing fees, royalties and expanded global participation. Licensing agreements tend to accelerate, or even increase, the payback on research and development expenditures, and as such they could stimulate further technology advancements.

In the longer run, the benefits of licensing are not so clear. Technology transfer may become a significant issue. Some countries are extremely fast at incorporating new knowledge and gaining experience on a broad front, despite the best efforts of the

Foreign Relationships of U.S. Firms

Country	Licensees	Subsidaries	Affiliates	Sales Agreements	Country Total
Belgium	1				1
Brazil	1				1
Canada			1		1
England	3	2		1	6
Finland	1				1
France	2	2	1		5
India	1			1	2
Ireland			1		1
Israel	1		1		2
Italy	1			1	2
Japan	3				3
Mexico		1		1	2
W. Germany			1		1
Yugoslavia	1				1
Total	15	5	5	4	29

Source: DOC/OIRA Industry Survey

licensor to protect his position. If these same countries also have lower labor costs or other special advantages, they may pose a competitive threat to the U.S. Investment Casting Industry in the future. However, the technology has continued to advance and the leading U.S. firms have maintained, and in some cases extended, their lead.

The 10 subsidiary and affiliate relationships, through financial, technical and/or marketing integration, are more complicated than direct licensing agreements. Like licensing, large firms are behind these relationships. Here again, the U.S. technological lead is demonstrated. The connected concerns may share research and development, patents, tooling and/or capital. The arrangement may also be part of a global marketing strategy. In at least one case, a foreign subsidiary was established to finish and market castings that were initially semi-finished in the United States. By so doing, the U.S. firm maintains close control over certain highly competitive state-of-the-art production technology while participating in foreign markets.

The four sales agreements shown in the table were reported by three medium sized U.S. firms. The agreements call for the marketing in the U.S. of investment castings produced in foreign countries. The single joint venture, between an American and Japanese firm, is not reflected on the table.

Offset Agreements

One area of growing concern, particularly to aerospace related investment casting suppliers, is the increasing demand for offsets by foreign governments when purchasing U.S. defense and related equipment. In defense trade, offsets are defined as a range of industrial and commercial compensation practices required as a condition of purchase of defense articles and defense services. These practices may include: coproduction, countertrade, technology transfer, mandatory subcontracting, overseas investment, licensing or other arrangements for the transfer of advanced production processes and management skills.

A number of firms in the aerospace sector cited specific examples of lost investment casting sales due to offset agreements between U.S. defense prime contractors and foreign governments. In these cases, the U.S. investment casting producer is the primary supplier of investment castings to the prime defense contractor for their respective defense systems. However, as part of the offset agreements, the casting producer found their investment castings displaced by foreign manufactured castings. Not surprisingly, two of the four Canadian investment casting firms responding to a survey for this report noted that offset agreements with the U.S. dramatically increased their opportunity to quote on and consequently obtain orders. One Canadian firm in particular noted that a very significant part of their work was due to offset agreements.

In many cases, offset agreements are invisible to the investment caster. However, as most military aircraft and gas turbine engine exports include offsets in one form or another, the investment casting sector is particularly vulnerable to the specific conditions of offsets agreed to between aircraft or engine companies and foreign governments. While the industry probably has enjoyed an overall increase in sales thus far, the long term trend of increasing offset demands could be detrimental in terms of both sales and the technological lead of U.S. investment casting firms.

We draw this conclusion because offsets have contributed to the worldwide overbuilding of aerospace production capacity. Should the trends previously witnessed in steel, autos, petroleum and other overbuilt global sectors prevail, the eventual correction to excess aerospace capacity may largely fall on U.S. firms. With many foreign governments committed to the construction and maintenance of national aerospace sectors, it appears all the more likely that the U.S. will absorb such a contraction, which could then adversely affect U.S. investment casting firms.

IV. PRODUCTION CAPABILITIES

Practical Capacity

Because so many differences are evident between individual investment casting foundries in terms of sophistication, capabilities, casting sizes and weights, materials cast, and markets served; it is difficult to present a meaningful estimate of practical capacity for the entire industry. However, two subsectors previously suggested for capacity measurement are "blades and vanes" and "aluminum" investment casters. These two sectors are specialized in their capabilities and market orientation.

There are only 14 blade and vane and 21 aluminum investment casting foundries in the United States of the estimated total of 182. Unlike less sophisticated foundries, blade and vane producers are equipped with special vacuum furnaces used for casting superalloys, state-of-the-art testing capabilities, and sophisticated process control and monitoring equipment. Aluminum investment casting, although easier to do and generally less sophisticated than blade and vane casting, has different production parameters than other metals. Aluminum is easier to pour, and it shrinks and machines differently from other metals, which has led many foundries to specialize. The conversion of an aluminum investment caster to another metal would require a major refitting of the foundry and retraining of the work force.

The other 147 investment casting plants in the U.S. comprise a more diverse and nebulous third subsector. The group contains mostly steel and stainless steel investment casters of moderate sophistication. However, three of these foundries cast titanium mostly into structural parts (mainly for gas turbine engines) and rank in sophistication with blade and vane producers. Further, the group includes foundries capable of producing castings weighing over 2,000 pounds as well as others that can cast only up to five or ten pounds. About half of the foundries in this group have fewer than 50 employees that produce predominantly the smaller sized (less than 20 pounds) investment castings. Some of these cast copper alloys or other metals into art or jewelry items.

The following table presents 1985 practical capacity and capacity utilization estimates for the three investment casting subsectors just described. For comparative purposes, capacity is presented in terms of units, pounds, and dollar value. Practical capacity, which is sometimes referred to as engineering or design capacity, was defined as the greatest level of output a plant can achieve within the framework of a realistic work pattern.

1985 Investment Casting Practical Capacity

Sector	Units (000s)	Weight (000s)	$ Value (millions)	1985 Capacity Utilization
Blade & Vane	5,747	11,551	$745.7	79.4%
Aluminum	20,220	46,160	321.3	72.4%
All Other	88,345	230,198	979.7	74.2%

Source: DOC/OIRA Industry Survey

The high average unit value of investment castings in the blade and vane sector ($130 per piece), which can be derived from the table, attests to the "high sophistication" that characterizes this sector. In contrast, the average unit value of aluminum investment castings is just under $16, and for all others, just over $11.

Interpreting Capacity

Estimates of investment casting capacity are very much a moving target that responds to a number of production variables and physical limitations. To control the production variables the surveyed firms were asked to make capacity estimates based on their "normal" product or market mix for investment castings. However, we also wanted to know how capacity estimates could change if unconstrained by the market. Thus, using their normal product mix as a starting point the firms were then asked to state how their capacity estimates could be increased or decreased if they had the flexibility to change production or product parameters. In addition, the firms were asked to characterize the dimensional limitations of their capabilities by indicating the maximum linear cross section and weight limits their facilities could accommodate.

Nearly every respondent reported that on a unit (or weight) basis "normal" capacity would decline the greater the geometric complexity of the part being cast. Greater part complexity makes every stage of the production process more difficult and time consuming and thereby lowers potential unit output. Capacity in terms of units (but not necessarily weight) would also decline as the weight of the casting is increased. The greater weight tends to increase processing times. Also, with the greater casting weight additional coats of refractory material must be added to the shell mold for strengthening. Individual plants will be limited to a maximum weight by their equipment. Other influences that lower capacity include: tighter specifications and tolerances, more vacuum heats, frequent product changes, more finishing operations and lower process yields (i.e., more rejected pieces). The inverse of any of these considerations would have just the opposite affect and increase capacity.

Investment casting foundries specialize by size and weight of casting. The capital and equipment needs of the foundries increase directly with the size and weight of the casting. Thus, the largest castings are made in much more capital intensive foundries than smaller castings. For this reason it is difficult to compare the capacities of foundries that cast over 300 pound pieces with those that cast only 5 or 10 pound pieces because their capabilities are so different. The same difficulty arises when comparing a foundry that can handle a 60 inch cross section with one that can only handle up to 10 inches.

The majority of investment casting houses (nearly 87 percent) handle less than 100 pound castings. These include all blade and vane producers and all but one of the aluminum foundries. Six foundries can handle over 300 pound castings. Two of these, pushing at the very limits of the technology, are capable of processing 2,000 pound weights. A weight distribution table of the plants by subsector follows:

Investment Casting Foundry Distribution
by Casting Weight Capability

Weight Range (in pounds)	Blade & Vane	Aluminum	All Other
	(number of foundries)		
under 50	7	15	114
50-100	7	5	10
101-200			12
201-300			6
over 300		1	5
Total Foundries	14	21	147

Source: DOC/OIRA Industry Survey

Lead Times

Peacetime lead times do not present a problem in either defense or non-defense applications in any of the three investment casting subsectors. Surveyed investment casting firms were asked to estimate average lead times, defined as the time interval between receipt of order and delivery to the customer. The lead time estimates are based on repeat orders as opposed to initial orders. Initial orders could be more than twice as long depending on the complexity of the die, which would be newly constructed. However, in a surge or mobilization emergency heavy reliance would be placed on available dies as existing weapon systems would be the ones that are surged or mobilized. Lead times were collected for both defense and non-defense applications.

The results by sector are as follows:

1985 Lead Times
(in Weeks)

Sector	Defense	Range	Non-Defense	Range
Blade & Vane	15	10-24	15	10-24
Aluminum	14	6-20	12	6-20
All other	13	8-18	11	4-17

Source: DOC/OIRA Industry Survey

Lead times tend to expand or contract in a direct way with increases or decreases in capacity utilization. Since (practical) capacity utilization rates were about average in 1985, the lead times shown can be considered typical. These lead times are well within the acceptable range for the timely production of the weapons systems in which they are used. However, under different circumstances, such as a surge or mobilization emergency, lead times would expand to levels above those shown and we can not say with certainty that they will remain within acceptable limits. In a surge or mobilization situation, the most integrated firms (i.e., those that perform the most production operations in-house) will have the most control over the degree to which these lead times expand. The firms that contract out portions of their work are more at risk in times of peak demand to delays both in finding a suitable subcontractor and in receiving delivery of the completed work. The issue of subcontracting by investment casters is addressed indepth in Part VI - Supplier Relationships.

The survey respondents were also asked how lead times could be shortened. Their responses were placed into four broad categories: 1) add capacity, 2) improve efficiency, 3) add people, and 4) prioritize orders. Not all firms responded, however a representative distribution of responses for each subsector is as follows:

How To Shorten Leadtimes

Method	Blade & Vane	Aluminum	All Other
	(number of responses)		
Add Capacity	5	6	19
Improve Efficiency	5	6	20
Add People	3	4	1
Prioritize	1	1	2

Source: DOC/OIRA Industry Survey

Adding capacity is not a quick method to shorten lead times and would be of limited utility under emergency conditions. However, for many plants the addition of capacity was the only option cited in their response. The other methods included more viable options, some of which can be planned for and implemented during times of national emergency. Options to shorten lead times are as follows:

Improved Efficiency
1) reduce inspection and testing requirements
2) increase welding allowances
3) relax specifications
4) increase production volumes
5) reduce machining and tooling lead times
6) place orders consistently
7) improve buyer/seller communications
8) reduce blueprint revisions

Other
1) stockpile alloys
2) add people
3) prioritize defense orders

In another effort, the Department of the Army surveyed 62 major investment casting end users that produce major weapons systems. The respondees reported that lead times are actually about twice as long as reported by the investment casting firms. The added time is accounted for by the ordering cycle (9 weeks for new orders), transportation time (3 weeks), finishing work done by the end user (4 weeks), and inspection of the investment casting (3 weeks).

The average total lead time for investment castings (as reported by 53 defense prime contractor survey respondents) was 24 weeks. The 24 weeks lead time was longer than average lead times reported for other kinds of castings: die castings (17 weeks), permanent mold (23 weeks) and sand castings (14 weeks).

Ramp-Up Time

Ramp-up is the time (in weeks) it takes to reach practical capacity production potential from production at current capacity utilization rates. Ramp-up time can be used as an initial indicator of the investment casting industry's production surge capabilities. It can also provide insight into the inevitable expansion of lead times in a surge or mobilization environment. Although the capacity utilization rate is perhaps the major determinent, ramp-up times can be extremely variable from one plant to another as a host of individual foundry characteristics, such as sophistication, plant integration, the availability of metals cast, location, and other considerations come into play. In general, however, for any given capacity utilization level, the more sophisticated the plant, the longer the ramp-up time is likely to be.

Ramp-up times ranged from none for plants operating at 100 percent (five foundries) to 60 weeks for one of the blade and vane foundries. Of the 14 blade and vane plants, nine reported ramp-up times of six months or more. In contrast, only four of the 21 aluminum foundries and only eight of the 26 "all other" foundries (that were reviewed) reported ramp-up times of six months of more.

The blade and vane producers included two foundries operating at 100 percent that reported "none" for ramp-up times. Including these two facilities in the tally for this subsector's ramp-up time resulted in a sector average of 21.2 weeks. Their removal caused that average to rise to 30.9 weeks and capacity utilization to fall from 79.4 to 72.8 percent.

The extended ramp-up time of this sector is cause for concern. The blade and vane sector is unable to meet surge or mobilization targets, as will be shown in Part V of this report. Lead times will most likely expand to unacceptable levels in times of national emergency. The high technical sophistication of this sector, combined with intensive testing requirements for both military and commercial production, is the underlying reason for this situation.

Ramp-up times for the three subsectors were reported as follows:

Ramp-Up Times

Sector	Average	Range
	(in weeks)	
Blade & Vane	30.9	5 to 60
Aluminum	16.4	0 to 28
All Other	19.2	0 to 52

Source: DOC/OIRA Industry Survey

Capacity Conversion Capability

Capacity conversion capability is defined as the ability of a manufacturing plant to convert capacity from non-defense to defense production. When this capability is substantial it can be viewed as an important strategic asset and even deterrent to conflict that significantly enhances our national security.

In measuring capacity conversion capabilities for investment castings, a limiting factor is the relatively small size of the commercial base compared to the military. For blade and vane and aluminum foundries, military production is estimated to comprise nearly 60 percent of sales. Add to this "essential civilian" production, which is substantial since both of these subsectors are oriented toward aerospace applications, and very little commercial base remains for potential conversion. As for the "all other" foundries, defense production is estimated to be only about 20 to 25 percent of output. Thus, conversion capability is not limited by lack of commercial base in this subsector.

In determining conversion potential, much hinges on the technical similarities of the commercial and military product. A great deal of product similarity of this nature exists in both the blade and vane and aluminum subsectors. The "all other" subsector contains many individual foundries where product similarity is found. However, many other foundries in this subsector ship only small quantities of investment castings to defense or none at all. For them such a comparison cannot realistically be made. In light of these foundries, defense production experience is another, though less tangible consideration for determining conversion potential.

Prior defense production experience can greatly reduce the time it takes to convert, even if commercial product is substantially different from the military product.

The table that follows shows three levels of capacity conversion capabilities and the number of plants identified in each level by subsector. The first level indicates those plants currently dedicated to defense production. These plants have no commercial production to convert and therefore no conversion capability. The second level includes plants for which the commercial and military products are essentially the same. These plants could convert to military production in a relatively short time, although substantial retooling may be required on a selective basis. The third level lists plants that would need to add people and/or equipment to make the conversion, in some cases by substantial amounts. The great bulk of responses fitting into this level are in the "all other" subsector. Many of these foundries lack defense production experience altogether. Considerable time and expense would be required in terms of new equipment, testing capability and

Conversion Capabilities

Capability	Blade & Vane	Aluminum	All other
	(number of plants)		
Already dedicated defense	5	2	1
Can readily switch	8	7	23
Need people/equipment	1	4	34

Source: DOC/OIRA Industry Survey

retraining of the labor force to bring this group into defense production. However, the ability of "all other" foundries identified in the first two levels appears more than adequate to meet almost any conceivable emergency defense requirements.

An important corollary to conversion within plants is conversion between plants. Stated differently, this is the "fungibility" between individual plants. The investment casting plant appears to be rather fungible where the lighter weight, less sophisticated product is produced, but much less so between more sophisticated plants. As already mentioned, plants tend to specialize by casting weight, material and sophistication. This gives individual plants a wide latitude to differentiate from their competition. Although considerable product overlap is evident in less sophisticated foundries, direct head-to-head competition is somewhat restricted by the narrowness of most end-markets combined with a limited number of buyers. As a result, many foundries, out of necessity, have adopted flexible production strategies which allow them to participate in a broader range of end markets. For these foundries, predominantly producing parts under 50 pounds, plant fungibility appears to be quite extensive.

The more sophisticated foundries are much less flexible in terms of both their product output and market orientation. Sophisticated plants spend much time and money searching for a technical "edge". Although several plants may compete head-to-head in bidding for any given order, there are many products only one foundry produces because of a special capability, proprietary knowledge or patent protection. Some fungibility exists within sharply defined subsectors, although these similarities are difficult to delineate when comparing any two plants. Even within sharply defined subsectors a great deal of product differentiation can be found.

For example, blades and vanes are made in many different sizes from many different material compositions. Their characteristics and processing also vary depending on their use in high or low-pressure sections of an engine. The single and polycrystal casting capability which dominates the production of hollow-core blades and vanes used in the hot, high pressure zones of the most advanced gas turbine engines, is currently located at only four foundries in the United States and one in England. (Note: A capability is now being developed at an additional foundry in the U.S., another in France and a third in Japan.) These special techniques, which are at the very edge of the technology, have little in common with the casting of low-pressure zone blades and vanes (which are sophisticated in their own right). Thus, fungibility between the high and low pressure investment casting plants is virtually non-existent.

In general, plant fungibility for the more sophisticated foundries is highly individualistic and restricted to a limited number of items. Also, in a surge or mobilization emergency, the issue will in all liklihood be moot as any surplus capabilities of these sophisticated plants (for which only a "thin" base exists) are quickly put to use.

The ability to convert a less sophisticated plant into a more sophisticated plant would require an extensive refitting of the foundry and retraining of the labor force. The time and cost would be prohibitive except under a general mobilization, in which case such an upgrading may be necessary.

V. SURGE AND MOBILIZATION CAPABILITIES

Surveyed investment casting firms were asked to estimate their surge and mobilization production capabilities, and to identify production bottlenecks that could impede their reaching targeted production levels. Definitions of surge and mobilization production capabilities are as follows:

> SURGE PRODUCTION CAPABILITY - The maximum sustainable level of defense production an "existing" investment casting foundry can acheive in six months following "surge" day, while normal non-defense deliveries are maintained. Procurement actions for additional materials to sustain surge production levels are initiated on surge day. Idle equipment may be activated, repaired, or upgraded, and new or used equipment purchased and installed if possible in the six month time frame. Labor may be hired to operate around the clock and weekends allowing for necessary equipment maintenance and downtime. Minimum defense target is two times peacetime defense production level.

> MOBILIZATION PRODUCTION CAPABILITY - The maximum realistic increase of sustainable defense production an investment caster can acheive in the 24 month period following a declared national emergency. Government financial assistance and prioritization of construction materials and outfitting equipment is available. Existing manufacturing buildings may be enlarged or converted, new buildings constructed and plant equipment acquired. Critical labor skills are to operate at maximum sustained production levels. Minimum defense target is four times peacetime defense production level.

Surge and mobilization capabilities were tabulated for the three subsectors: blades and vanes, aluminum, and all other foundries. Problems in meeting surge and mobilization targets were found in the blade and vane sector, notably for foundries supplying the high pressure sections for gas turbine engines, and the aluminum sector. No pressing problems were found in the all other sector, although some defense important foundries reported difficulties. A sector by sector analysis follows.

Blades and Vanes

Blade and vane producers cannot meet surge or mobilization targets. In a surge situation these foundries collectively reported they could only increase production by 35 percent, and in a mobilization, by only 269 percent. Of particular concern, the four major high pressure blade and vane producers reported their capabilities as only about half the percentage figures for the total sector.

Surge Capability

Size Range	1985's average monthly defense production rate	Percentage % Gain at 3 months	Increase % Gain at 6 months
Under 1 lb	102,203	17.6%	47.1%
1 - 5 lbs	64,384	7.5	19.5
6 - 10 lbs	16,050	11.4	20.8
11 - 20 lbs	1,291	19.1	29.4
21 - 50 lbs	184	10.1	22.3
Over 50 lbs	0	0	0
Total	184,112	13.5%	35.0%

Mobilization Capability

Size Range	1985's average monthly defense production rate	Percentage Increase % Gain at 6 months	% Gain at 12 months	% Gain at 24 months
Under 1 lb	102,203	78.6%	197.6%	350.9%
1 - 5 lbs	64.384	44.9	61.0	172.9
6 - 10 lbs	16,050	47.1	122.8	125.1
11 - 20 lbs	1,291	156.4	241.9	349.8
21 - 50 lbs	184	163.0	221.1	322.3
Over 50 lbs	0	0	0	0
Total	184,112	64.6%	143.7%	269.0%

Source: DOC/OIRA Industry Survey

Surge Bottlenecks

Seven foundries reported they could meet surge targets, five could not, and two failed to report. Production bottlenecks differed from foundry to foundry, but centered around the wax pattern production operation followed closely by the casting/melt stage. A ranking of surge bottlenecks is as follows:

1. PATTERN PRODUCTION/ASSEMBLY - Three foundries named this as their number one bottleneck. The major problems were shortages of trained labor and space. One firm indicated a wax injection machine would be needed at a cost of $40 thousand and four months lead time.

2. CASTING/MELT - Two foundries named this as their number one problem. One of these reported an additional vacuum furnance would be needed at a cost of one million dollars, and a lead time of six months. Other problems include space and labor limitations.

3. SHELL FORMING - One plant named this as its major bottleneck, citing limited space as the chief problem. Other firms mentioned dipping operations, drying and labor as additional concerns.

4. DIE TOOLING - One firm reported die tooling as its major production constraint and that it would take six months to correct. Two other firms mentioned this as either the second or third ranking problem. One of these said it would need a 50 percent increase in die tooling capabilities that would take nine months to acheive at a cost of $400 thousand.

5. FINISHING - One investment caster mentioned finishing as a major bottleneck, noting that equipment, labor and additional space would be needed. One other foundry named this as its number two constraint stating that additional skilled labor would be needed.

In addition, several foundries were concerned about the availability of superalloy materials in a surge situation. Two foundries indicated in general that space and labor constraints would be problems in every phase of their production operations.

Mobilization Bottlenecks

Eight blade and vane producers reported they could meet mobilization targets after 24 months, one at a cost of over $60 million dollars. Four said they could not, and as in surge, two did not answer. By far, the most serious mobilization bottleneck is the vacuum furnaces essential to the melting and casting operations. The shell forming operation was named as a distant second bottleneck. The ranking of the bottlenecks is as follows:

1. CASTING/MELT - Five blade and vane plants reported this operation as their major constraint to achieving mobilization targets, mentioning vacuum furnaces as the chief cause. The furnaces may cost from $750 thousand to $18 million and could take from 12 to 24 months to obtain. Several firms mentioned space and labor as additional constraints. Two firms ranked this operation second among their bottlenecks and one as third.

2. SHELL FORMING - Three producers named shell forming as their primary bottleneck, identifying drying space, dipping equipment (robots) and labor constraints. Two other firms named this as their number two bottleneck and one firm as its number three bottleneck. The cost of equipment, as reported by three firms, ranged from $250 thousand to $6 million with lead times ranging from 13 to 24 months.

3. PATTERN PRODUCTION/ASSEMBLY - Two firms named this as their major bottleneck. Both indicated additional wax injectors would be needed, one noting that a new machine would cost $880 thousand and take 24 months to acquire. Two other casters, ranking this operation as their second and third most serious bottlenecks, reported they would also need wax injection machines. Labor was mentioned as a concern by two of the firms.

4. DIE TOOLING - Two firms said this would be their chief constraint, noting they would need space, equipment and labor to correct the problem. One of these indicated the correction would take 24 months and cost $1.1 million. Two firms reported this as their second most important bottleneck.

5. FINISHING - One firm mentioned this as its primary bottleneck and that it would cost $24 million (for equipment, space and labor) to eliminate. One other firm ranked this as its second bottleneck, noting it could be alleviated with the addition of trained labor.

In other areas, only two foundries expressed any concern about raw materials and one of these was concerned about on-location storage space.

Aluminum

Aluminum investment casters cannot meet surge or mobilization production targets, but do come closer to targeted levels than the blade and vane investment casters. Aluminum casters reported they could collectively increase defense production by 91 percent in a surge and by 270 percent in a mobilization.

Surge Capability

Size Range	1985's average monthly defense production rate	Percentage % Gain at 3 months	Increase % Gain at 6 months
Under 1 lb	320,564	27.9%	91.9%
1 - 5 lbs	64,765	30.6	77.7
6 - 10 lbs	14,663	32.6	90.0
11 - 20 lbs	4,888	50.5	154.5
21 - 50 lbs	2,444	72.0	186.3
Over 50 lbs	0	0	0
Total	407,324	29.0	90.9

Mobilization Capability

Size Range	1985's average monthly defense production rate	Percentage Increase % Gain at 6 months	% Gain at 12 months	% Gain at 24 months
Under 1 lb	320,564	91.9	143.6	278.2
1 - 5 lbs	64,765	77.9	120.8	226.1
6 - 10 lbs	14,663	92.3	154.4	234.3
11 - 20 lbs	4,888	148.1	249.0	356.2
21 - 50 lbs	2,444	184.1	307.0	440.5
Over 50 lbs	0	0	0	0
Total	407,324	91.0	142.6	270.3

Source: DOC/OIRA Industry Survey

Surge Bottlenecks

Six aluminum foundries reported they could meet surge targets, six could not, and nine failed to report. Production constraints varied somewhat from foundry to foundry, but the most serious commonly experienced problem was the shell forming process. A ranking of surge bottlenecks is as follows:

1. SHELL FORMING - Five aluminum investment casters ranked shell forming as their number one bottleneck. All indicated they would need additional space and equipment at costs ranging from $50 to $500 thousand and acquisition lead times ranging from 2 to 12 months. Robots, conveyor systems and drying space were listed as problem areas. Two firms mentioned labor would be a limitation. In addition, two firms named shell forming as their second major constraint and two others as their third constraint.

2. INSPECTION - Three aluminum foundries reported inspection and testing operations to be a major bottleneck. Two of these said skilled labor was the chief concern, one noting a training period would take six months and cost $50 thousand. The other reported that "cosmetic", as opposed to functional casting design considerations, have often increased his inspection and testing burdens. One firm said testing equipment would cost $250 thousand and take six months to obtain. Two other foundries identified this as their second and third bottlenecks.

3. PATTERN PRODUCTION/ASSEMBLY - Two firms identified this as their most serious bottleneck; three as their second, and two firms as their third. Space, equipment (such as wax injection machines and workbenches) and labor were cited as key problems. One foundry reported a wax injection machine would cost $100 thousand with a lead time of six months.

4. CASTING/MELT - One company named this operation as its major production constraint, citing casting equipment and preheat ovens as needed equipment. Three other firms identified this as their second ranking bottleneck stating that equipment, space and skilled labor were problems.

5. FINISHING - No firms identified finishing as their major bottleneck. However, three firms named this as their second most severe bottleneck. One firm said specifications could be simplified and production increased by eliminating cosmetic designs. Space and labor were also mentioned as problematic.

Mobilization Bottlenecks

Five aluminum investment casting foundries reported they could meet mobilization targets, seven could not, and nine failed to report. As in surge, shell forming was most often named the most serious bottleneck. A ranking of bottlenecks for the subsector is as follows:

1. SHELL FORMING - Four foundries identified shell forming as their number one bottleneck, citing space, skilled labor and equipment as constraints. One of these firms noted that air conditioning equipment in his drying area would be needed and take nine months to obtain. Two firms named this as their second major constraint, stating drying space and a conveyor line, each costing one million dollars and taking 12 months to acquire, would be needed.

2. PATTERN PRODUCTION/ASSEMBLY - Two foundries named this operation of their major bottleneck. Space, labor and equipment were named as the constraints, costing from $50 to $500 thousand and taking from three to 12 months to rectify. Three firms mentioned this as their second most critical bottleneck and three others as their third. Two firms said they would need wax injectors, one at a cost of $250 thousand and eight months lead time. One firm stated labor could be trained in 12 months for $60 thousand.

3. CASTING/MELT - One plant reported this as its number one bottleneck and that corrective action, adding preheat ovens and casting equipment, would cost one million dollars and take 12 months. Two firms named this as their second bottleneck.

4. DIE TOOLING - One foundry named this as its most severe bottleneck, citing subcontractor lead times as the major concern. Three other foundries each named this as their number three constraint. The availability of quality subcontractors was named as the key problem.

5. FINISHING - One firm identified this as its second bottleneck and two firms as their third. One firm reported additional water blast equipment would be needed, another that additional skilled labor would be required, and a third that space would have to be added to his facility.

<u>All Other Foundries</u>

Surge and mobilization capabilities for the all other sector was estimated from a sample of 26 plants, all of whom supply product to the military. The review showed the sector to be slightly short of surge targets, but far ahead of mobilization targets, acheiving target levels in less than a year. As this sector has substantial commercial shipments, in a "real" surge situation, prioritizing orders could allow them to expand defense production considerably above what is shown here. Of the 147 establishments in this sector, approximately 100 ship nothing or very little to defense.

Surge Capability

Size Range	1985's average monthly defense production rate	Percentage Increase % Gain at 3 months	% Gain at 6 months
Under 1 lb	867,532	61.3%	104.2%
1 - 5 lbs	616,107	42.9	76.4
6 - 10 lbs	407,718	42.9	72.1
11 - 20 lbs	231,040	78.6	120.5
21 - 50 lbs	106,460	72.4	107.7
Over 50 lbs	36,242	63.9	127.7
Total	2,265,099	55.3%	93.0%

Mobilization Capability

Size Range	1985's average monthly defense production rate	Percentage Increase % Gain at 6 months	% Gain at 12 months	% Gain at 24 months
Under 1 lb	867,532	300.0%	525.0%	780.3%
1 - 5 lbs	616,107	284.6	530.5	1,501.2
6 - 10 lbs	407,718	177.6	308.5	872.6
11 - 20 lbs	231,040	194.1	314.3	557.5
21 - 50 lbs	106,460	203.0	309.5	550.0
Over 50 lbs	36,242	156.4	266.3	554.1
Total	2,265,099	256.2%	451.8%	1,028.6%

Source: DOC/OIRA Industry Survey

Surge and Mobilization Bottlenecks

It should be understood that this subsector includes some very important foundries that could not meet surge or mobilization targets. These tend to be very sophisticated foundries that send a significant amount of their production to defense. The bottlenecks affecting these foundries are mostly of the same nature found in the blade and vane sector, particularly where vacuum furnaces are involved. Some of these foundries may need assistence in an emergency situation.

Of the 26 foundries reviewed, 14 were able to meet surge targets and 17 were able to meet mobilization targets. The major bottleneck for both a surge and mobilization is the shell forming operation. More firms actually identified die tooling and concern about the availability of subcontractors as their most serious problem in a surge, but far fewer named it as their second or third bottleneck. A ranking of bottlenecks is as follows.

Surge Bottlenecks

Rank	Operation	No. of firms ranking as First	Second	Third
1.	Shell Forming	5	6	2
2.	Die Tooling	6	1	1
3.	Inspection	3	4	3
4.	Casting/Melt	3	2	3
5.	Pattern Prod./Ass.	2	2	4

Mobilization Bottlenecks

Rank	Operation	No. of firms ranking as First	Second	Third
1.	Shell Forming	7	4	5
2.	Casting/Melt	5	3	3
3.	Die Tooling	5	2	2
4.	Pattern Prod./Ass.	2	5	2
5.	Inspection	2	3	2

Source: DOC/OIRA Industry Survey

Government Actions

Surge

According to the industry, the U.S. Government could help facilitate a surge by taking specific actions. Most often mentioned was provision for financial assistance at the outset of a surge, which if not forthcoming could cause unnecessary delays. Several foundries said Government sponsorship of a labor training center would be beneficial, and others said Government assurance of the availability of raw materials could help. Other firms mentioned that the Government should reduce paperwork and "red tape", ensure specifications are functional (and not cosmetic), forecast requirements, and prioritize the purchase of used equipment. Several firms also stated the availability of subcontractors for die tooling should be closely supervised.

Mobilization

In a general mobilization, the U.S. Government would need to play an immediate active role by assisting investment casters with funding, labor training and the prioritizing of equipment purchases, subcontracting and investment casting output. Most firms indicated financial assistance would be required. Others indicated that a labor training center would be critical to their increasing operations. Several said specifications should be geared for functional requirements, avoiding cosmetic specifications. Some firms also mentioned paperwork should be streamlined and reduced. Other actions for the Government to consider include forecasting requirements, and planning the availability of raw materials.

VI. SUPPLIER RELATIONSHIPS

Subcontracting

Investment casting firms often subcontract production operations such as die tooling, heat treating, and finishing. Most investment casters also perform these operations in-house and use subcontracting to accommodate production overflow, for special situations, as a lower cost option, or simply because they lack a particular expertise. Even companies that integrate the full range of production under a single roof subcontract occasionally if only as a contingency for potential vital equipment breakdowns, which could otherwise be very expensive in terms of lost output.

Survey data on subcontracting does not treat new die fabrication as a direct element in the production process. However, firms frequently subcontract this activity to avoid the overhead burden involved in keeping a fully tooled and staffed machine shop. On the other hand, firms realize the engineering input and worker skills required at this stage are essential to the steady operation of their plant. They will, therefore, usually maintain a capability in this area for repairs and some die making.

We believe two general rules apply: 1) smaller investment casters tend to subcontract die fabrication with greater frequency than larger firms as larger firms are better able to absorb the overhead, and 2) the more sophisticated the die the more likely it will be subcontracted because machine shop costs rise proportionately with die sophistication.

Slightly more than 50 percent of firms in the aluminum and all other sectors of the industry reported significant levels of subcontracting activity. For the most part, the levels of subcontracting were not very high, and in no case did they exceed 35 percent of the value of production. However, 90 percent of blade and vane producers reported at least some subcontracting, although the levels were also low. Most firms in the blade and vane segment are large firms that utilize subcontracting to supplement in-house production capabilities or as a means of maintaining a smooth flow of production through the plant. Many also lack a hot isostatic pressing (hip'ing) capability which must therefore be outsourced.

The table below summarizes often subcontracted operations by individual investment casters in the three industry sectors. Responses in the "None" row mean the plant does not "normally" subcontract any of the indicated services.

Subcontracted Processes by Industry Sector
(Percentage of Positive Responses)

Subcontracting	Blades & Vanes		Aluminum		All Other		Industry	
Processes	No.	%	No.	%	No.	%	No.	%
None	3	16%	7	47%	13	50%	23	38%
Die Tooling	2	10%	3	20%	1	4%	6	10%
Heat Treating	7	37%	0	0%	8	31%	15	25%
Machining/Fin.	5	27%	4	27%	3	11%	12	20%
All Other	2	10%	1	6%	1	4%	4	7%
Total	19	100%	15	100%	26	100%	60	100%

Source: DOC Industry Survey

Heat treating processes, including hip'ing account for a large number of positive responses in the blade and vane and other categories. (Aluminum castings are not heat treated.) For these sectors, while excluding die tooling, the share of heat treating constitutes over 30 percent of all subcontracting activity. Heat treating facilities are very expensive and require high volumes of parts to run economically. For this reason, smaller plants utilize the heat treating services of specialized heat treating companies most often. Larger plants use subcontracted heat treating to supplement in-house capabilities, or for specialized processes (such as vacuum heat treating). The reported percentage of heat treating that was subcontracted by surveyed blade and vane and ferroalloy plants accordingly varied from 3 percent of output to as much as 20 percent, with the norm located at about 10 percent.

Finishing activities such as grinding and surface coating are also subcontracted by a number of firms. As in die fabrication the equipment and skilled labor requirements are expensive and may be difficult to fully justify for some firms, who look to outside sources to supplement their in-house capabilities. One industry engineer noted that customers are beginning to demand that more of this and other processes be done on the premises to facilitate control over quality and scheduling. If this is true, firms will probably integrate further over the next ten years. Such an eventuality could put smaller plants at a further disadvantage.

Another significant subcontracting area is in ceramic core production. Ceramic cores are used in conjunction with wax patterns to produce hollow spaces in castings, and they must be produced to the same level of precision as the wax patterns themselves. The technology used in their production is distinct enough to warrant plant specialization. Accordingly a number of firms have established separate plants specializing in the production of precision ceramic cores which are then shipped to investment casting plants.

Strategic Materials

Direct material inputs in the investment casting process include metal alloys, waxes, and shell materials. These materials are normally purchased by the investment casting firm in an immediately usable form from specialty suppliers. A large number of independent firms produce these materials in a variety of types and prices, although supply concentration is high in the quality end of the market.

Import reliance for certain materials is high. However it is important to distinguish between materials that are required to produce relatively unsophisticated castings and those needed to produce high quality special application castings. The latter normally require carefully processed metal alloys with special properties, whereas less sophisticated castings can rely on standard industrial materials which are readily available from domestic sources. Some of these materials used to cast aerospace quality investment castings include high and low alloy steels, nickel and cobalt base superalloys, aluminum base alloys, and titanium alloys.

The table below shows a general overview of the distribution of metals used in investment casting:

Metals used in Investment Casting Percentage Shares (Dollar Value)		
Ferrous (incl. stainless)		35%
Non-Ferrous		65%
Aluminium	15%	
Nickel/Cobalt	20%	
Copper	15%	
Other (incl. Titanium)	15%	
TOTAL		100%

Source: American Metal Market

These figures cover all investment castings. If aerospace and military castings were shown separately, the share of nickel and cobalt based superalloys, aluminum alloys and titanium metals would be much greater. A breakdown of metals used by the largest firms surveyed in 1985, (which account for a majority of aerospace production) indicates that vacuum cast superalloys accounted for over 44 percent of total material usage by value. Stainless and other high quality steels, titanium, and aluminium alloys accounted for the bulk of the remaining metals used in the high quality end of the market.

Superalloys and other "exotic" casting metals are normally purchased in a readily melted form from a number of specialized metals producers. These suppliers include Certified Alloy Products (Long Beach, CA), the industry's largest supplier, Excalibur Metals (Bettendorf, IW), another leading supplier of alloy steels and high temperature metals, and Inco Alloys International (Huntington, WVA), a sister company of Wiggins Alloy of the U.K.

Critical nonferrous base metals include: cobalt, nickel, aluminum, and titanium. Important alloying elements include: chromium, lithium, molybdenum, columbium, tantalum, silicon, tungsten, and manganese.

The reliability of foreign supplies of these materials during wartime depends on a range of political, economic, and military/logistical considerations. A significant proportion of U.S. imports of critical metals are produced by allied nations such as Canada and Australia. On the other hand, some of the most important base metals for aerospace applications such as cobalt and most of the range of more exotic alloying metals are imported from politically unstable countries and/or countries that from a logistical standpoint we may find it difficult to import from in a national emergency.

To reduce the vulnerability of the United States economy to any sudden loss of these imports, the federal government manages a National Defense Strategic and Critical Materials Stockpile Program. This program, which is updated on an annual basis, is designed to stockpile 94 materials in amounts sufficient to supplement available domestic supplies for military and essential civilian requirements during a three year global conflict. Theoretically, this program should ensure a steady supply of critical metals to the defense related investment casting industry during a surge and subsequent mobilization period. Of the strategic metals used in investment casting of critical military parts and components, only molybdenum (of which the U.S. has large reserves) is not subject to government stockpiling.

In addition to the stockpile program, private metals producers have developed scrap recovery programs to supplement supplies of imported metals. In some cases these recycled metals represent considerable percentages of domestic consumption. For example, a major supplier of highly pure metal ingots for the investment casting industry, Certified Alloy Products of Ohio, extracts the majority of its metals from recycled materials.

Other Materials

Pattern Materials

Approximately thirty wax wholesalers produce and/or import raw wax materials into the United States and blend them for industrial use. Most of these firms are well established and are located in the Northeast region of the United States (with a concentration in the New York and New Jersey areas). Of these general industrial wax firms, about 15 identify investment casters as important customers. (None of whom are devoted entirely to the industry.) Large petroleum and chemical corporations such as Exxon and DuPont also produce industrial waxes, but for reasons that are outlined below, these firms are insignificant suppliers to the investment casting industry. In addition to these sources, some of the largest investment casting firms, such as Howmet, blend waxes in-house.

A variety of vegetable, mineral, and synthetic waxes are available to American investment casting firms in blended and unblended states. However, about 80 percent of the raw material supplies that go into the production of these waxes are currently imported. The two natural waxes most often used in metals casting, candelilla and carnauba, for example, are entirely foreign sourced. They are primarily imported from Mexico and Brazil. Additional quantities are also supplied from markets in other parts of South America and West Africa. On their own, candelilla and carnauba are not suited as an investment casting pattern wax because of their extreme melting point specificity and brittle structure. They are essential however, for use in blending a number of "paraffin", or oil based waxes.

Paraffins, which embrace a broad range of properties, are the most popular base waxes for investment casting pattern materials used in the United States. The U.S. currently has a large domestic production capacity in paraffins, however imports supply between 75 and 80 percent of the total market, and the import share of paraffin waxes used by the investment casting industry is probably even higher than this figure.

The underlying cause of this large import share lies both in the lower cost of imports and in the marketing patterns of the major domestic chemical and petroleum producers. Domestic paraffin producers have outpriced themselves from the general market for paraffins that is comprised of small and medium sized industrial consumers, and as a consequence, domestically produced paraffins are typically sold to a limited number of bulk consumers (investment casting firms not included). Rather than paying the full retail price (which is estimated to be about 20 percent above the world market price) these preferred customers receive an industry discount that is unvailable to smaller firms forcing them to purchase at higher (full retail) prices or look offshore for supplies.

While the supply of domestic paraffins remains high priced, imported paraffins can easily be purchased from a wide variety of low wage producer countries around the world including some in Portugal, Spain, South America, and China. These imported paraffins are cheaper, more stable in terms of price and supply, and more readily available.

Mold Materials

Mold materials, or ceramic shells, are composed of binder materials and refractory aggregates. Binders are predominantly silicates or silica sols that are either water or ethanol based. Refractory aggregates are usually based with fused silica. Like pattern materials, shell ceramics are chosen for basic properties that influence the accuracy of the casting. These properties include heat resistance, low thermal expansion, compatability with both the wax pattern material and the casting metal, purity, and flow and covering characteristics.

The type of metal being casted and the shape and section thicknesses of the part will also influence the choice of shell material. Aluminum castings, for example, are more delicate than high strength metal alloys and are consequently vulnerable to deformation during the post-casting "knock-out" stage. To overcome the risk of part damage, aluminum casting firms have developed mold mixes that produce shells which can be removed from the casting with less effort than is employed for sturdier metal alloys. Other metals, and other castings also have unique requirements which are taken account of in the mixing of the ceramic slurry.

Although it is the most widely used ceramic base for shell molding, fused silica alone does not possess the necessary properties for accurate casting. To produce these properties, investment casters typically mix fused silica with traces of other refractory elements. Zircon and zirconia are the most widely used of these metals, but alumina, chromic oxide, and magnesia are often used as well.

Fused silica is produced in large and competititvely priced supplies in the United States. An established network of wholesalers throughout the country ensures a reliable supply to the foundry industry. On the other hand, primary production of fused silica is limited to a small number of firms that are heavily concentrated in the Tennessee Valley, such as Combustion Engineering Metals. (The sale of C.E's fused magnesium operations to the Japanese chemical producer, Tateho Chemical Industries Co., in November 1986, excluded C.E.'s fused silica production facility in Greenville TN.) The geographic and corporate concentration of the primary stages of fused silica production increases the risk that sudden labor unrest or natural disasters could disrupt supplies.

Foreign dependence in ceramic mold materials is generally a function of the availability and vulnerability of supplies of the strategic metals that are added to the fused silica base. Zircon is heavily imported from Australia and to a lesser degree the Union of South Africa. Domestic consumption of this metal was valued at $18 million in 1986 with ceramics and refractories accounting for 13 percent and 30 percent respectively. A significant number of firms surveyed in 1985 indicated that shortages of these strategic materials and/or large fluctuations in their prices were not uncommon. Although time and money has been expended in finding alternative sources or substitutes for these materials. In the majority of cases, however, shortages did not result in serious disruptions of production.

VII. TECHNOLOGY ASSESSMENT

High precision and complex casting at a competitive price is an important advantage of investment casting. Enhancing this advantage to expand markets within the broader metal casting and metal working industry hinges in large measure on further improving the level of technology applied to the investment casting production process, and the attention firms give to materials research, and product development. Many firms within the industry (particularly the largest firms) have budgeted considerable funding for research and development in these areas in recent years, and at an accelerating rate. The table below summarizes research and development expenditures for the industry between 1981 and 1985.

Expenditure on Research and Development
($Thousands)

Year	Expenditure
1981	$ 6,825
1982	$ 7,839
1983	$10,987
1984	$19,817
1985	$22,390

Source: DOC/OIRA Industry Survey

The more than threefold increase in expenditures on R & D over the five year period is, on the one hand, reflective of healthy growth in the industry generally, but is also high in its own right. Investment casting firms, particularly in the higher precision aerospace and gas turbine engine markets, have recognized the link between process technologies, quality, and price on the one hand, and the expansion of sales within the high technology markets on the other. Research efforts are often coordinated closely with major purchasing firms to develop mutually satisfying improvements in casting technologies.

A few examples drawn from some of the larger firms illustrates this point. Hitchiner Manufacturing has recently embarked on a five year cooperative research joint venture with General Motors, potentially a major commercial customer, to develop new products and processes for the automobile. Howmet Corporation has facilities focusing exclusively on R&D including a new "Casting Technology Center" employing over 150 scientists, engineers, and technicians. Howmet has also listed "cooperative research efforts with customers" as a major priority. Precision Castparts is involved in a number of R&D programs with major aerospace customers and the U.S Air Force. Three major projects are with the Air Force's "Technology Modernization Program" (Tech Mod) and embrace research in a wide range of advanced casting and process technologies.

Key Technologies

In general industry research efforts are focused on a) reducing costs and improving productivity, b) improving the investment casting product, and c) expanding into new markets. These efforts can be divided into process technologies, materials research, and product development.

Process Technologies

Production technologies are primarily focused on automation and improvements in the accuracy of various stages of the production process from die fabrication to final testing. Evidence from survey responses indicates that widespread interest exists in new automated technologies relating to inspection, wax injection, pattern assembly, casting, materials handling, and management control such as inventory planning. In general the level of automation in investment casting firms remains below that found in comparable ferrous and nonferrous foundries. However, since Hitchiner Manufacturing built the industry's first mechanized casting plant in 1961 (which included automated shell building, a conveyor system, and mechanized melting and pouring), the level of automation has steadily increased.

Surveyed firms most frequently cited automated inspection equipment as a desirable new technology. Testing is an essential (and in many cases contractually mandated) stage in quality control, however it tends to be time and labor consuming. Radiographic testing, which is required for all aerospace castings is particularly time consuming and normally involves a high degree of repetition. So called "Real Time Imaging" is a computerized process which would significantly speed the through-time associated with X-ray testing of parts, and several major casting firms are now independently developing this technology.

Other testing procedures such as flourescent penetrant baths and dimensional probes are being adapted to computerized control and mechanized conveyor systems. As these innovations are perfected and integrated into the production process the cost and time devoted to testing should drop, at the same time that reliability and accuracy improve. Whether or not a firm will choose to invest in this kind of machinery depends, however, on the level of precision demanded and the relative cost of testing. It is clear that competitive pressures within the aerospace market will force many firms to do so.

Materials handling equipment is another major focus of R&D, particularly since large structural castings (which can currently weigh more than 2,000 lbs) are difficult to handle by manual means. Both Howmet and Precision Castparts have installed robot dipping machines that can handle pattern and mold weights up to 5,000 lbs. As the current trend toward large integrated castings gathers momentum over the next five years we can expect a greater emphasis on robotic dipping and conveying machinery.

CAD/CAM technologies are predominantly in the development stages. As with other fields of R&D CAD/CAM research is conducted either independently by firms, or increasingly, in cooperation with large customers. Precision Castparts through its Air Force Tech Mod programs, and Howmet and Hitchiner through various joint projects, are developing computer software programs to facilitate process control, and to boost productivity. Precision Castparts, for example, is currently developing plans for a completely automated and integrated production process which would rely heavily on centralized computer processing. In another development, a "Solidification Modeling Program" software package has been developed which allows engineers to "test" various gating configurations in simulated casting runs, thus avoiding costly and repetitive use of prototypes.

Computer technology is also being adapted to management and cost control programs. One major firm, for example, has achieved significant productivity gains through a computerized "just-in-time" inventory program. Computer information systems integrating data from all areas of production and management are also being developed at the largest firms. These information networks should improve communication and streamline the functioning of individual plants.

Metals Research

Metal alloy research is primarily centered on developing new alloys with superior qualities than existing alloys, and in developing methods of strengthening and otherwise improving the integrity of castings.

Superalloys are mostly nickel and cobalt based alloys that combine strength, anticorrosive, and temperature resistant qualities needed in the harsh environment of gas turbine engines. Few metals combine these qualities as well as superalloys, and for this reason, nearly all gas turbine blades and vanes are cast from them. Superalloys and titanium are frequently casted and melted under vacuum conditions to limit impurities and defects. Perfecting this process and bringing its cost down are current focuses of research and development in the furnace industry as well as in investment casting firms.

Aluminum is also rapidly becoming an important investment casting metal. As one example, Howmet has had some initial success in proving the commercial viability of aluminum investment castings, particularly in large structural applications. The firm also recently produced aluminum based blades and vanes for Pratt & Whitney's PW 2037 gas turbine engine deployed on the Boeing 757 passenger plane. Research is being conducted in areas of new aluminum alloys as well. One hopeful example of this is in aluminum-lithium alloys.

Titanium is an important alloy that is increasingly being utilized in advanced fighter aircraft applications for its high strength to weight ratio, and low radar signature. Titanium is also an important alloy as the only structural metal that does not corrode on contact with "composite materials." As newly developed "composites" gain ground in aircraft structural applications titanium investment castings should experience a parallel growth in demand. The large aerospace investment casting firms are currently expanding capacity and developing expertise in casting of titanium which should position them to take advantage of this market as it begins to take off over the next ten years.

Metals Strengthening Technologies

To overcome the relative structural weakness of investment castings compared with forgings, casting firms have developed and utilized various heat treating processes. One important application among these processes is hot isostatic pressing . In this process, the casted part or component is placed in a heated vessel and subjected to pressures of up to 15,000 psi. The combination of heat and pressure strengthens the metal by restructuring the molecular arrangement within it and improving grain alignment.

HIP'ing and other heat treating procedures are now commonplace in both the United States and overseas. As it is a very expensive procedure that is used sparingly it is nearly always subcontracted by firms with the exception of a few large plants that have in-house capabilities. HIP, Ltd. of Chesterfield in the U.K. is a major subcontractor in the British market.

Controlled solidification processes such as so called "Single Crystal" technologies, and "Directional Solidification," are other means of strengthening castings. In these procedures the solidification of the metal is controlled through heat "sinks" or other means producing a metal part that closely approximates the molecular structure of a single crystal. This advanced technology, which is currently limited to a handful of larger firms, has already proved its usefulness in extending the life of airfoils used in the "hot" sections of gas turbine engines. (Howmet produced more than 200,000 such single crystal blades by mid 1985.)

Pattern and Investment Materials

Pattern and slurry materials research is centered on efforts to produce higher performance materials that reproduce surface detail and dimensional configurations with greater accuracy and at lower per unit costs. Pattern materials have traditionally been paraffin and organic based wax compounds that are cheap and relatively abundant. Little known research has gone into development of new compounds that have better thermal expansion characteristics and higher recoverability then existing compounds, however industry spokesmen and survey responses indicated that interest exists. One hopeful area is in polysterene compounds. These petroleum based "foams" are used in much the same manner as wax patterns and are dipped in the ceramic slurry and fired out to leave a mold. The advantage in polysterene is the ease with which patterns can be produced and stored, and the completeness with which the pattern material can be expelled from the mold, and unlike wax materials which can leave carbon deposits on the surface of the mold after burn-out, polysterene vaporizes completely at relatively low temperatures. This process is currently being developed by a leading British investment casting firm and is arousing interest on this side of the Atlantic as well.

Other processes have been designed to take advantage of low melting point materials. A successful example of this technology is "mercast", a process that employs frozen mercury as the pattern material. Like polysterene, the flow characteristics of mercury generate remarkably accurate castings. One drawback to this process is that the use of these pattern materials will also require the development of new slurries and binders that can better cope with the metal and the temperatures involved than can conventional shell materials. Reliance on new shell materials potentially presents its own set of unforseen supply deffiociencies.

Ceramic slurry materials are not currently a great focus of attention. In general terms areas of focus are control of thermal expansion, surface quality, and bonding characteristics. Most investment casting firms produce their own slurry mixes from basic raw materials (such as fused silica and zirconia) and tailor these mixes to meet individual casting needs.

Product Development

Product development and marketing efforts are also linked to research and development. This is made most clear by expanding large structural castings (primarily used in aerospace markets at the moment), but applies to smaller parts as well. The trend toward large structural castings is based on the ability to produce a single integrated part in place of a component assembled from a number of individually forged and/or machined parts. This drastically reduces the time and cost associated with multiple stage fabrication, cuts material waste, and also provides structurally sounder parts from a wider range of metal alloys.

The technological challenge of large integrated castings is related in large measure to the physical volume and weights of the parts. As was indicated above, these castings can currently weigh more than a ton, and consequently require automated dipping and conveying machinery. The weight of pour metals also places tremendous pressures on investment shells which must be stronger than conventional investment materials. Further, the size of the castings necessitates the investment in new equipment, from vacuum furnaces to knock-out machinery, that is capable of handling large pieces.

The market for large structural parts is likely to grow at a healthy rate as the industry and customers gain experience in this area. As is the case in other areas of research and development, current high volume customers take an active if not leading role in promoting the development of large integrated castings. Large integrated castings are at the forefront of developments in the new generation of high performance gas turbine engines and aircraft structures. The position that investment casting firms take in these developments is linked not only to their commitment to the technology, but to the working relationships and reputations they hold with their customers.

Precision Castparts has been an industry leader in this field, and has developed strong relations with some key gas turbine engine producers such as Pratt & Whitney. Other major investment casting firms have developed capabilities in this area as well. Arwood has focused a recent $25 million expansion on large structurals, which is slated to boost current output by as much as 60 percent. Howmet also recently entered the large structural market and has planned major expansions. The firms output has included the integrally cast "stators" used in the gas turbine compressor stages of the TF-30 engine used in the Air Force's F-14 and F-111. Other large components produced by Howmet and leading structural producers include afterburner structures, bypass ducts, forward frames, and compressor casings.

Advanced Ceramics

Advanced ceramics are newly developed materials which may someday replace metals in a number of investment casting applications. Advanced ceramics are fabricated from a range of inorganic compounds (primarily silicates) that are among the most abundant in the earth's crust. In addition to potential performance improvements, use of these abundant materials can potentially free the U.S. aerospace industry from a large portion of its current foreign dependence on strategic metals.

Blended ceramic materials have properties which make them particularly suitable candidates as replacements for parts that are currently investment cast in gas turbine and other engines. These properties include superior temperature resistance, wear resistance, and anticorrosive qualities and lighter weight. Unfortunately these positive qualities are undercut by their current very high process cost and propensity to fracture "catastrophically" without warning. Unlike most metals, advanced ceramics do not generally show signs of fatigue in advance of material breakage. Consequently, when breakage occurs it is sudden and catastrophic. This potential risk of failure has thus far limited the usefulness of advanced ceramics in high performance and/or dangerous applications such as aircraft engines.

Approximately 10 percent of current sales of ceramic parts and components are in the heat engine market. The remaining market is centered on electronic components (packaging of integrated circuits, capacitors, resistors, sensors etc.), and engineering products and parts such as cutting tools and wear parts (including antifriction bearings), and ceramic fiber composites. Japanese firms dominate in both production and R&D in these commercially viable fields. Western European firms are showing ceramics interest as well.

In the United States, research in advanced ceramics is well underway by at least 30 or 40 firms in a wide range of fields. However, lack of progress in overcoming the "sudden failure" problem has pushed commercial production of ceramic parts for jet engines probably several decades into the future. For the present time, commercial applications of advanced engineering ceramics are likely to remain focused on vehicular engines and parts including turbocharger rotors, pistons and piston rings, cylinder lines, and other small stationary engine parts. In some cases these products are currently investment cast.

Nevertheless, it is unlikely that ceramic parts and components will make serious inroads into the investment casting market for advanced parts (such as turbine blades and vanes) any time soon. What use advanced ceramics will find in the investment casting industry will probably remain restricted to the narrower scope of ceramic cores and inserts, which is now an important branch activity in the industry.

Competing Processes

In choosing from alternative metal forming techniques, engineers balance a number of qualitative and cost considerations. In the case of investment casting, a balance must be struck between what are usually high up front unit costs, and the indirect savings (in machining, material, etc.) the investment cast product entails. The investment casting also has important qualitative advantages such as dimensional accuracy and shape complexity that are typically included in weighing these costs.

The potential advantages of investment casting over competing metal forming processes are summarized below.

Advantages of Investment Casting

Qualitative:

a) wider range of metals
b) highest dimensional tolerances
c) highest level of surface detail
d) high shape complexity
e) high level of consistency between castings
f) near net shape

Cost Savings:

g) lower metal scrap rates
h) reduced finishing requirements
i) reduced assembly requirements

These advantages vary from one casting application to another according to dimensional tolerances, other specification requirements, and production volume. In some cases, alternative casting processes may be qualitatively acceptable substitutes and more cost effective. At the margin however, other factors may weigh heavily enough to override them. Precision requirements or the difficulty of working a material can sometimes be beyond the capabilities of competing processes. Gas turbine engine blades and vanes are a good example of how some applications can best take advantage of investment casting. The thinness of metal sections, dimensional precision and accurate curvature, hollow internal structure, toughness of the metals used (nearly always nickel or cobalt base superalloys), and the low degree of variance that can be tolerated from one casting to another, are simply beyond the cost effective means of other casting and forging processes.

By reducing scrap rates associated with metal removing procedures of alternative machining processes, investment casting provides considerable materials cost savings. Scrap rates for investment casting are among the lowest of any metal casting process, at around 3-5 percent, and are significantly below those associated with forging and machining, which can run as high as 70 percent. Part of the cost savings is due to the lower weight of most casting that stems from design advantages, and the rest derives from reductions in the machining steps. The table below illustrates these advantages in the case of a selected sample of automotive parts.

Comparative Weight and Cost of Castings and Weldments

Material	Weight Ferrous Casting lbs	Weight Weldment lbs.	Casting Cost Savings (%)
600 hp Chain Drive Housing Knee	49	45	78
600 hp Housing Cover	42	46	76
1000 hp Dsl Block and Base	10,620	11,420	74
600 hp Dsl Block and Base	3,375	3,340	66
1000 hp Turning Gear Hsg.	104	110	65
600 hp Chain Drive Housing	287	295	56

Source: Steel Castings Handbook, 1980, Steel Founders Society of America

Other competing metal casting processes share in these metal cost savings as well, however investment casting provides the highest degree of precision and lowest amount of post-casting finishing. These factors, low scrap rates, and high precision, explain why the investment casting process is a standard practice in the production of fine jewelry. Thus, whereas the ease with which dies can be produced and modified is much greater in the case of most alternative casting methods, the level of precision that is attainable is inadequate. (Appendix C describes these alternative processes in greater detail and highlights relative advantages and disadvantages.)

The advantages of investment casting become apparent in comparing the process to competing forging and other machining techniques. In some cases, other techniques are simply too difficult because of the hardness of the metal involved or the intricacy of the shape. The case of gas turbine engine blades and vanes was illustrated earlier. In a number of other cases including lower value commercial castings, these advantages still hold. For example, low value, but complex parts like keg valves, and hand gun triggers, can be mass produced much more cheaply and more reliably by investment casting than by either forging or stamping.

By producing a single integrated casting, investment casting can eliminate numerous steps in the fabrication of a component, greatly reducing machining requirements, machining time, and conserving a significant quantity of material (and the energy associated with producing that material) by nearly eliminating scrap. The elimination of multiple machining and other stages associated with forging and other fabrication processes, reduces both the costs connected with expensive tooling and the skilled labor needed to tend and operate it.

In a general mobilization emergency, the investment casting process could be used much more extensively as a "substitute" in numerous applications now performed by machine tool processes, thus relieving some of the pressure that would fall on the machine tool industry in such a situation. So called "near net shape" parts that are produced by investment casting require only minimal post-casting finishing such as drilling, grinding, or welding. The following table illustrates these advantages in the case of selected automotive diesel crankshafts.

Comparison of Material Loss and Machining Time
of Forged Steel and Cast Iron Crankshafts

	Steel Forgings			Iron Castings			Savings	
Type Diesel Engine	Rough Weight lbs.	Finish Weight lbs.	Machine Time hours	Rough Weight lbs.	Finish Weight lbs.	Machine Time hours	Material lbs.	Machine Time hours
6 cyl	2,520	657	160	700	637	80	1,800	80
6 cyl.	1,344	287	100	256	216	30	1,017	70
3 cyl.	469	133	73	120	96	24	312	49
6 cyl.	1,316	330	75	364	354	34	976	41
4 cyl.	630	168	84	159	126	51	439	33

Source: Steel Castings Handbook, 1980, Steel Founders Society of America

In this illustration, the average material savings per "ton" rough weight cast amounts to 2.9 tons, and the average machine time saved (again per ton rough weight cast) is 447 hours. However, this comparison is actually between forged and "sand" casted crankshafts. Investment castings normally involve more complex shapes as well as lighter weights than these items. This implies the savings in material and machining time realized by investment casting would be significantly greater than other casting techniques. In fact, the complexer the shape, the more the savings are likely to be, <u>especially</u> in machining time.

Another illustration of this advantage is the case of a steering arm. This part was formerly produced by welding seven individual parts that were cut from bar stock and tubing. Redesign of the part as a single casting eliminated 127 separate operations from purchasing, receiving, and storing, to materials handling, fabrication, machining, and inspection. In addition, the elimination of fabrication stages also eliminates the cost of carrying extensive parts inventories.

The substitution of single castings for fabrications is a major source of market growth for the investment casting industry. As industrial manufacturers, and machinery producers in particular, become more aware of the cost and quality benefits to be gained from investment casting relative to competing processes, it is likely that investment casting will become a standard practice in a widening range of manufacturing activities.

VIII. CONCLUSIONS AND RECOMMENDATIONS

The major conclusions of this assessment are as follows:

- Although about 160 firms are believed to manufacture investment castings, the top five firms accounted for over 60 percent of total industry sales in 1985. Four of these top five firms also accounted for about 85 percent of the blade and vane market.

- Investment castings are essential components of gas turbine engines, comprising over 40 percent of the weight of recent models. The manufacture of hollow-core blades and vanes by the single- and polycrystal investment casting techniques for use in the hot, high pressure zones of gas turbine engines makes the modern engine possible.

- U.S. firms lead the world in investment casting technology. This lead is in large measure the result of close collaboration by several investment casters with the large aircraft engine companies in developing and applying new technologies.

- This technological lead has a positive qualitative impact on defense capabilities, and has conferred competitive advantages on U.S. investment casting firms in the world aerospace market.

- The investment casting of large integrated titanium pieces for structural applications as well as special aluminum alloys, which reduce weight, increase speed, and lower fuel consumption, are facilitating further improvements in the gas turbine engines.

- Because the U.S. has such a limited production base for hollow-core blades and vanes and various other highly sophisticated investment castings, leadtimes for these products can be expected to rise to unacceptable levels in a surge or mobilization emergency as demand quickly overtakes supply capabilities.

- Imports are reportedly a concern in the higher volume industrial markets (e.g., golf clubs, hand guns, value bodies, etc.). Several firms reported investment castings in these markets are entering in increasing numbers, although official trade numbers are not collected at this level of detail to substantiate these claims.

- The investment casting sector is dependent on foreign suppliers for numerous metals (most of which are stockpiled), wax and wax blending materials, and selected ceramic shell making additives, such as zirconium. Although this is of little concern during peacetime, in an emergency normal supply channels could be disturbed, causing lead times to grow.

- In the future the trend may favor larger firms as the technology continues pushing toward larger sized castings, improvements in the production process, and greater plant integration. These trends will require firms to have a larger sales base over which to spread overhead costs.

- Despite advances in automation and improvements in certain operations, the investment casting process remains labor intensive, particularly for the pattern making/assembly operation. (Especially if high production volumes are involved.) Labor was found to represent over 60 percent of the value added for the industry as a whole, compared to about 40 percent for all manufacturing.

- In an emergency, the investment casting process can be used as a "substitute" for numerous applications now performed by machine tools, saving roughly three tons of material (by reducing scrap) and 500-1,000 hours in machining time for each ton of material investment cast.

Based on the above conclusions, the following recommendations are made for Department of Defense consideration:

- Detailed advanced preparedness planning with blade and vane investment casters is required, particularly with the hollow-core producers. This planning should incorporate defense requirements based on priorities highlighted is the DOD Critical Items List.

- Provision should be made for immediate financial assistance to this sector in an emergency to prevent unnecessary delays in adding production capacity.

- Raw material requirements should be established for each plant. Planning should include allocating stockpiled materials and identifying <u>domestic</u> sources for other materials, such as waxes and certain shell materials, as contingencies in the event of an interruption to foreign supplies.

- Consideration should also be given to identifying investment casting die makers and planning their availability on a priority basis. In addition, consideration should be given to establishing purchase plans for vacuum furnaces, shell forming equipment and other processing equipment, which could reduce the sector's response time.

- o As a follow-up investigation, a closer examination should be made of the investment casting's potential as a "substitute" for machine made products, which are critical to defense needs in an emergency.

- o Programs such as "Mantech" and "IMIP" (Industrial Modernization Incentives Program) that develop new technologies and make production processes more efficient and responsive to defense requirements should be expanded with additional investment casters. The current DOD program with Precision Castparts to develop real-time imaging, high-pressure waterblast shell removal and CNC finishing will help maintain the tecnological leadership of the United States in this area.

APPENDIX A

Detailed Investment Casting Process Description

The Investment Casting Process

Die and Pattern Production

Die construction is a vital link in the production process. Most often this stage is subcontracted to firms that specialize in die construction and which consequently have the skilled labor, and the utilization rates necessary to justify heavy investment in machine tools. Dies can run in cost from a few hundred dollars to well over $200,000, depending on the level of complexity. In any event, dies that are used by investment casting firms must be built to exacting specifications and consequently represent a significant fixed cost.

Most often the pattern is produced by injection of a paraffin based wax into the die. Wax injection is typically carried out by using wax injecting machines which ensure an adequate flow of wax into the die. When the wax has solidified it is removed from the die in a labor intensive process of disassembly. The process is then repeated for the next part. Hollow passages may be introduced into the pattern by insertion of preformed ceramic "cores". These cores are often produced by subcontractors for inclusion in specific patterns. After casting the ceramic core is then removed by mechanical means or chemical leaching.

Many large investment casting patterns are produced by wax "welding" separately injected component patterns into a complex assembly. This activity is probably the most labor intensive stage in the process and may require moderate to high skill levels and experience. Smaller castings are often assembled into a "tree" by attaching a number of wax patterns to a central sprue through a system of "gates". These gates and the sprue will then serve as channels for the molten metal. Small channels called "risers" are also typically attached to the part or assembly to allow an overflow of metal and to ensure even casting.

Investment

After the pattern or "tree" has been assembled the entire system is dipped in a ceramic refractory slurry to create a shell around it. The dipping is done in stages, first using a very fine solution to capture surface detail on the pattern, and gradually upgrading the grittiness of succesive layers. Between coatings, a granual layer of "stucco" material is "rained" onto the shell to encourage bonding of succesive layers. The pattern is dipped anywhere from three to eight times depending on the thickness required.

Pattern Removal and Firing

After achieving a desired thickness, the pattern/shell monolith is allowed to harden. The system is then inverted in an autoclave and the wax is melted out. In the firing stage the ceramic shell is cured, and any wax remnants are burned out of the mold. Melted wax is often channeled into retrieval containers for recycling.

Casting

Prior to casting, the mold is typically preheated to compensate for thermal shock. Preheating of the mold requires furnace equipment and space, both of which were cited as constraints by surveyed firms. Most ferroalloys can be cast simply by pouring molten metal from a ladle into an opening in the inverted shell, however special alloys (e.g., titanium and superalloys) may have to be casted in a vacuum to limit impurities. In other cases, casting of parts with thin walls may be assisted by centrifugal techniques.

Knock-Out, Finishing and Heat Treating

After cooling, the ceramic shell is removed from the part in a process known as "knock-out". Knock-out may involve sand blasting, vibrational removal, chemicals or other means depending on the frailty of the part. If any ceramic cores were inserted into the mold these will be removed as well by chemical or mechanical means. Any protruding remnants of the gates and risers are then cut off and surfaces are finished. "De-gating" and finishing is usually carried out in small metal workshops within the plant.

It may be necessary or desireable to strengthen the casting after finishing. This is most often done by heat treating the part. (See Technology) One important variety of heat treating used in investment casting is Hot Isostatic Pressing (HIP'ing) in which the part is subjected to both high pressures and heat. Like preheating, these processes require large amounts of space and equipment and are often partially subcontracted to meet the turnover load.

Testing

The finished part is subjected to a series of elaborate tests to ensure the metallurgical integrity and dimensional precision of the casting. This stage is both capital intensive and time consuming but is a critical part of a process that is oriented toward a high degree of precision. In many cases military regulations will specify a range of required testing. These nondestructive tests include radiographic, dye-penetrant, fluorescent, and visual and dimensional procedures, each of which requires a trained staff and support equipment. Where appropriate, these tests may indicate that additional machining and finishing should be carried out or that the part must be rejected.

APPENDIX B

Strategic Materials

Frequently Investment Cast

Cobalt

COBALT

SELECTED STATISTICS: 1982-1986

(Short Tons)

	1982	1983	1984	1985	1986 (e)
U.S. Production	436	362	440	449	600
Imports	6,435	8,611	12,655	8,854	7,500
Exports	300	412	336	314	400
Apparent Consumption	5,726	7,856	8,948	7,846	7,700
Price ($/lb)*	8.56	5.76	10.40	11.43	8.50
Net Import Reliance	92	95	95	94	92

* Average annual spot for cathodes.

Source: Bureau of Mines

Cobalt is an important base metal used in the production of high-strength and temperature resistant superalloys which accounted for 36 percent of reported consumption of this metal in 1986. Within the investment casting industry, the primary end use of these alloys is in turbine blades and vanes.

A recycling cobalt processing capacity exists in the United States with 12 processors actively supplying an estimated 150 domestic industrial consumers. Domestic mine production ceased in 1971. Import dependence has hovered at between 92 and 95 percent since 1982, and would currently be 100% were it not for a healthy recycling effort.

About 40 percent of U.S. imports come from Zaire, another 16 percent comes from Zambia, 13 percent from Canada, and 6 percent is processed in Norway. High reliance on imports from a few developing countries has in the past led to erratic supply and price fluctuations with serious effects on investment casting activities. For example, the price of cathode cobalt which started the year 1986 at $11.00/lb dropped to $3.90/lb by August of the same year. At present the price remains low due to a world surplus of cobalt supplies.

The U.S. has estimated reserves of approximately 1.4 million tons of land based cobalt, although the majority of this is in subeconomic concentrations. Cobalt recovered from recycling operations contributed approximately 9 percent to estimated U.S. consumption in 1986. Nickel can be substituted for cobalt to an extent in the production of superalloys for use in turbine blades and vanes. Another potential substitute is advanced ceramics, although turbine applications of these materials remain in the research stage of development.

Nickel

NICKEL

SELECTED STATISTICS: 1982-1986

(Short Tons)

	1982	1983	1984	1985	1986 (e)
U.S. Production					
Refined	44,456	33,400	44,933	36,382	35,000
Secondary	43,000	50,000	55,167	57,183	39,200
Imports	129,787	152,333	176,715	157,690	140,000
Exports	37,356	23,359	31,638	21,745	3,000
Apparent Consumpt.	181,000	201,000	210,000	219,200	184,000
Price ($/lb)*	2.24	2.20	2.22	2.26	1.90
Net Import Reliance	76	75	69	72	78

* New York Dealer Price.

Source: Bureau of Mines

Nickel, like cobalt, is used to produce a wide variety of high strength, temperature resistant superalloys. Nickel is also used in large quantities to produce more common lines of stainless steel alloys due to the metal's impressive anticorrosive properties. Approximately 39 percent of primary nickel consumed in the United States went into stainless and alloy steels; 31 percent to nonferrous alloys; and 22 percent into electroplating.

Nickel is widely used in the investment casting industry as a substitute for cobalt in the production of superalloys for turbine blades and vanes. Due to nickel's anticorrosive properties, the metal is also used to cast parts for marine applications including structural components used in naval aircraft.

Three domestic firms produced primary nickel in 1986, supplying approximately 340 industrial consumers. One of these nickel producers shut down after a preliminary 2 1/2 month run due to continuing declines in the world price of the commodity. The remaining two producers produce nickel primarily as a byproduct of copper processing activities. Domestic nickel consumption declined more than 10 percent in 1986 to 184,000 short tons.

Import reliance for nickel has increased since 1984 and was 78 percent of apparent consumption in 1986. Primary import sources include Canada (44 percent), Australia (14 percent), Norway (11 percent), and Botswana (10 percent). World reserves of nickel are very large, although a considerable percentage is difficult to extract or recover (deep sea manganese nodules are a potentially large source of nickel). U.S. reserves are also estimated to be very large, however the most likely development sites are located in "environment sensitive" states such as Oregon, California, and Minnesota. In the meantime an ongoing world market surplus of nickel has eroded the spot price, which dropped 16 percent in 1985 alone. Under these circumstances it is unlikely that further development of reserves will be undertaken in the short term.

Considering the world surplus supply of nickel, the existence of large untapped reserves in the United States, and the fact that over 65 percent of foreign sources are reliable OECD nations, it is reasonable to conclude that import reliance does not pose a great risk to investment casting supplies or to national security more generally. (Nickel is also stockpiled by the Federal Government.) In addition, over 20 percent of current consumption is supplied through recycling reclamation indicating a large potential recovery capacity. To an extent, nickel alloys can be substituted for by nickel-free specialty steels and titanium, although such substitution could impose a cost penalty on casters.

Titanium

TITANIUM

SELECTED STATISTICS: 1982-1986

(Short Tons)

	1982	1983	1984	1985	1986 (e)
U.S. Production	15,600	13,966	24,326	23,257	17,500
Imports	1,354	1,199	2,677	1,717	1,700
Exports	8,096	7,830	7,333	10,384	14,000
Reported Consumpt.	17,328	16,072	24,713	21,606	20,000
Price ($/lb)*	5.55	3.60	4.00	4.00	4.00
Percent Imports	**	9	9	***	14

* Yearend, 1982; reported sales, 1983-86.
** Withheld to avoid disclosing company proprietary information.
*** Net Exports.

Source: Bureau of Mines

Titanium is a relatively new material in industrial applications that is characterized by light weight and strength characteristics similar to high grade steels. The high strength to weight ratio has made titanium a useful structural material in the production of a widening range of military and aerospace products. As of 1986, somewhere in the range of 80 percent of titanium was used in the production of jet aircraft engines, airframes, and space and missile applications, and include a growing number of investment casted parts. The remaining range of products (equal to about 20 percent of the total) includes chemical processing, power generating, marine, and ordnance equipment. Investment castings of titanium are most often alloyed with aluminum, vanadium, molybdenum, iron or manganese.

Domestic titanium sponge production decreased in 1986 and the industry is presently characterized by approximately 45 percent excess capacity. Large inventories of the metal account for this oversupply, which accounts in part for the decline in the spot market price for the metal in the last few years.

The value of sponge metal consumed in the U.S. was approximately $160 million in 1986. Sponge was produced by four firms with production in Nevada, Ohio, Oregon, and Washington. Ingot production was carried out by three of these firms plus seven other firms located throughout the United States. Twenty-four firms produced titanium mill products or castings, with production located primarily in the east central region of the country.

Titanium sponge is most widely obtained in the U.S. from rutile and ilmenite ores. Rutile, which is the primary domestic source of titanium metal, is mined in one location in Florida and recovered as a byproduct of ilmenite at two other locations. Less than 15 percent of rutile is used to produce titanium. Ilmenite is produced by two firms in the United States, however less than 2 percent is used to produce titanium metal. The bulk of domestic titanium and titanium dioxide is used in the production of pigments and other non-metallic products.

The United States was a net exporter of the metal in 1985. Imports as a percentage of apparent consumption, however, were 14 percent in 1986. Almost all titanium sponge imported into the United States comes from Japan, with limited amounts imported from the Soviet Union and others. Recycling sources of titanium metal are very reliable and well established and in 1986 these sources exceeded domestic consumption. Government inventories are relatively high.

The combination of low import reliance, high inventories, low capacity utilization, and minimal share of total ore devoted to sponge production leads to the conclusion that titanium supplies are not facing any near to medium term danger. In the event of an emergency it is likely that any slack not provided through these sources can be picked up by diverting titanium bearing ore from paint pigment production to metal generation.

ALUMINUM

SELECTED STATISTICS: 1982-1986

(Thousand Metric Tons)

(e)	1982	1983	1984	1985	1986
U.S. Production					
Primary	3,274	3,353	4,099	3,500	3,100
Secondary	782	820	825	850	830
Imports	878	1,091	1,477	1,420	2,000
Exports	748	776	734	908	730
Apparent Consumption	4,370	5,035	5,279	5,174	5,291
Price ($/lb)*	0.47	0.68	0.61	0.49	0.56
Percent Imports	7	17	7	16	26

* U.S. market spot.

Source: Bureau of Mines

Aluminum and aluminum alloys are used in a wide variety of applications as a structural material, packaging, electrical components, and parts for machinery and equipment. Investment casted aluminum products are to some extent still being developed, but potentially have a broad market in aerospace, particularly where intricate and light weight structural components, metal matrix composites, and aluminum-lithium alloys are concerned.

Aluminum production requires supplies of alumina bearing ores upon which the United States is almost entirely import dependent. As of 1986 net U.S. import reliance in bauxite stood at 97 percent of apparent consumption. Although over 500,000 tons of bauxite was produced domestically, virtually none of this contributed to the supply of aluminum as the vast majority was used to produce industrial abrasives. Bauxite and alumina is imported primarily from Australia (76 percent of alumina), Guinea (45 percent of bauxite), Jamaica (32 percent of bauxite and 10 percent of alumina), Brazil (6 percent of bauxite), and Suriname (7 percent of alumina). Domestic resources of bauxite are believed to be inadequate to meet long term demand, however virtually inexhaustable reserves of aluminum can potentially be recovered from alumina bearing clay which is currently a subeconomic resource.

In 1986, 11 companies operated 21 primary aluminum reduction plants with 3 firms accounting for 63 percent of total production. High world inventories, low prices, and high production costs, have contributed to a decline in domestic production since 1984. Import reliance in aluminum metal is not very high, however it has increased as a percentage of apparent consumption from 7 percent in 1984 to 26 percent in 1986. In addition, heavy reliance on foreign imports of bauxite are not reflected in these figures (see above). Primary aluminum import sources include Canada (56 percent), Japan (10 percent), Ghana (5 percent), and Venezuela (4 percent).

As per above, domestic aluminum requirements cannot be met by domestic bauxite resources. The United States does possess vast subeconomic reserves of aluminum bearing ores. In addition, a thriving recycling industry provides a steady stream of aluminum metal (this source yielded 830 thousand tons of aluminum, equal to 16 percent of apparent consumption, in 1986). Titanium and specialty steel products can be used to replace aluminum in some structural applications, however performance characteristics may be compromised.

Alloying Metals

SELECTED ALLOYING METALS USED IN INVESTMENT CASTING

(1986 Import Penetration Levels)

Mineral	Import Penetration	U.S. Vulnerability to Foreign Disruption	Stockpiled	U.S. High-Grade Resource Adequacy to 1999
Manganese	100%	Yes	Yes	Insignificant
Tantalum	91%	Yes	Yes	Large
Chromium	82%	Yes	Yes	Small
Tungsten	62%	No	Yes	Small
Vanadium	54%*	Yes	Yes	Small
Silicon	35%	No	Yes	None
Beryllium	16%	Yes	Yes	Insignificant
Lithium	**	Yes	No	Small
Molybdenum	**	Yes	No	Small

* 1984 level. ** Net Exporter

Source: Bureau of Mines

The table above summarizes import dependency information for nine essential metals used in the production of steel and/or aluminum and titanium alloys commonly used in investment casting.

A wide range of metals are used as alloying agents in the production of superalloys, specialty steels, titanium alloys, and aluminum alloys that are used extensively in the investment casting industry. Many of these metals are essential in imparting properties to an alloy without which performance would be substandard. A large number of these materials, such as manganese and chromium, are predominantly imported and either have no substitutes, or are substituted for only by other import dependent metals. Most of these metals can be recovered from subeconomic domestic ore deposits, but the cost is in most cases starkly prohibitive, and lack of technology or capacity makes short term generation impractical.

APPENDIX C

Competing Production Processes

Casting Alternatives

Sand Casting

This technique involves molds made of sand to which varying amounts of resinous binders have been added. The process is most widely used for iron and steel castings and is applicable for parts ranging in weight from a few pounds to several tons in weight. Sand castings of great complexity and moderate dimensional accuracy are readily produced.

Permanent Mold Casting

This process makes repeated use of a permanent mold constructed of two halves hinged or clamped to each other. The materials used in this process are generally limited to aluminium and magnesium, although some kinds of iron, zinc, and lead are sometimes cast by this process. The average size of these castings varies from as low as half a pound to about 12 pounds.

Plaster Mold Castings

This method of casting utilizes molds made from a slurry of gypsum. The castings have fine finishes and surface detail like investment castings and is particularly suitable for thin wall parts—down to about 1/16 inch thick. These castings are usually small and rarely range beyond 20 pounds. Most plaster mold castings are made from copper alloys, however aluminium and magnesium are also common.

Die Casting

This process is often considered the best alternative for high production rates. Molten metal is forced under pressure into closed metallic dies. Because the dies are solid the complexity of shapes which may be handled is more restricted than with either sand or investment casting. Most die castings are made of zinc or aluminium. Aluminium parts can be cast to weights of 100 pounds and zinc castings up to as much as 200 pounds.

Electroforming

This is essentially a plating process. A core pattern of the part is placed in a chemical bath and a metal skin is deposited on the core to the desired thickness. The assembly is then removed from the bath and core is separated from the deposited metal. The resulting part is a thin walled self supporting structure with inside dimensions matching those of the core.

Forging

Forging involves the working of either hot or cold metal into the desired shape by impact or pressing. Most metals can be forged. Forging processes are generally more expensive than casting, but they produce parts with greater strength and toughness.

"Open-die" forging is usually used for large heavy pieces such as shafts and die blanks. This simple technique involves turning the part as a mechanical hammer pounds out a shape.

"Drop-forging" is a refinement on the open die process using a hot billet and repeated poundings from a mechanical hammer. Part weights produced in this fashion can range from as low as an ounce to several tons.

Other forging techniques include "upset-forging" (to produce small to medium sized parts from rod stock), "cold heading" (similar to "upset-forging"), "press-forging" (employing pressure rather than impact to squeeze hot metal placed between two dies, commonly used to produce parts weighing 25-30 lbs), and "impact extrusion" (in which a slug of metal placed in a die is subjected to the pressure of a punch, causing the metal to flow into the space between the punch and the die).

Stamping and Pressing

These two processes are used to cut or form metal sheet, plate and strip. A flat "blank" is prepared and the metal is then sheared or stretched into a die to attain the desired shape. The forming process is achieved either through stamping or drawing. The process is generally limited to metal thicknesses of less than 3/8 inch.

Powder Metallurgy

This involves the production of parts from metals in powder form by compacting the powder in a die to the desired form and heating (sintering) to fuse the powders together. A secondary press operation, called "coining', is sometimes performed on the sintered part. Most metals and many combinations of materials can be formed in this way. Parts can range in size from less than 1 inch to around 6 inches in diameter, and up to 5 or 6 inches in length.

Material Removal: Mechanical Machining

Machining involves the shaping of a part through removal of material. A tool constructed of a material harder than the part being formed is forced against the part causing metal to be cut from it. There are many kinds of machining processes involving lathe type spinning action, milling (where cutting is done by rotating multiple-tool cutters), drilling, boring, and tapping. Grinding, honing, and lapping remove material with abrasives, which may be bonded in belts or rotating wheels (grinding), or in a fine abrasive stone (honing), or in a soft material with abrasive particles embedded in it (lapping).

Material Removal: Nonmechanical Machining

There are four basic nonmechanical processes: 1) in chemical milling the metal is removed by the etching reaction of chemical solutions on the metal; 2) electrochemical machining uses the principle of metal plating in reverse, the workpiece, instead of being built up by the plating process, is eaten away in a controlled manner by the action of the electrical current; 3) electrical discharge machining and grinding erodes or cuts the metal by high-energy electrical discharges; 4) lasers.

APPENDIX D

Industry Survey Instrument

Form ITA-9052
(2-86)

U.S. Department of Commerce
International Trade Administration

Form Approved:
OMB #0625-0158
Expires 6-30-86

INVESTMENT CASTING INDUSTRY

THIS REPORT IS REQUIRED BY LAW

This report is required by law (50 U.S.C. App. Sec. 2155). Failure to report can result in a maximum fine of $1,000 or imprisonment up to one year, or both. Information furnished herewith is deemed confidential and will not be published or disclosed except in accordance with Section 705 of the Defense Production Act of 1950, as amended (50 U.S.C. App. Sec. 2155).

General Instructions

1. It is not our desire to impose an unreasonable burden on any respondent. IF INFORMATION IS NOT READILY AVAILABLE FROM YOUR RECORDS IN EXACTLY THE FORM REQUESTED, FURNISH ESTIMATES AND DESIGNATE BY THE LETTER "E". Any necessary comments or explanations should be supplied in the space provided or on separate sheets attached to this questionnaire. Ensure that you reference the proper question if you use extra sheets. If any answer is "none", please indicate.
2. Report calendar year data, unless otherwise specified in a particular question. Parts II and III must be completed separately for each of your establishments that produce investment castings in the United States. Please make photocopies of forms if additional copies are needed. For Parts I and IV firms operating more than one establishment may combine the data for all establishments into a single report.
3. FIRMS WITH 50 EMPLOYEES OR LESS are required to answer ONLY the following questions: PART I—All, except that for questions four, five and six, report 1985 shipments only; PART II—All; PART III—Questions two, eight, nine, eleven, and thirteen only; PART IV—NONE.
4. In addition to the original report form to be returned to us, there is enclosed a file copy for your records. You are not legally required to fill out or retain this file copy. While it would be a convenience to the Government for a file copy to be made and retained for reference purposes, no assurances can be provided that file copies are exempt from compulsory examination pursuant to legal process.
5. Questions related to the questionnaire should be directed to Mr. Alex F. Evan, Industrial Specialist (202) 274-8225, Dr. Joel Morris, Industrial Specialist (202) 274-8209, Department of the Army, or Mr. John Tucker, Industry Analyst (202) 377-3795, Department of Commerce.
6. Before returning your completed questionnaire be sure to sign the certification and identify the person and phone number to contact your firm.
7. Return completed questionnaire by March 7, 1986 to:

U.S. Department of Commerce
International Trade Administration
Office of Industrial Resource Administration
Attn: Brad Botwin, Program Manager for
Industrial Capabilities, Room H3876
Washington, D.C. 20230

DEFINITIONS

BOTTLENECK—During a production expansion, the production process, operation or procedure, or material or labor requirement within your manufacturing establishment that would ultimately prevent or delay increased production.

CRITICAL OCCUPATIONS—Includes occupations for which you anticipate a potential shortage of qalified personnel during surge or mobilization. In general, this would include skilled occupations that require an extended training period.

ESTABLISHMENT—All facilities in which investment castings are produced. Includes auxiliary facilities operated in conjunction with (whether or not physically separate from) such production facilities. Does not include wholly owned distribution facilities.

FIRM—An individual proprietorship, partnership, joint venture, association, corporation (including any subsidiary corporation in which more than 50 percent of the outstanding voting stock is owned), business trust, cooperative, trustees in bankruptcy, or receivers under decree of any court, owning or controlling one or more establishments as defined above.

INVESTMENT CASTING—Production of industrial metal castings using expendable patterns and monolithic molds.

MOBILIZATION PRODUCTION CAPABILITY—The maximum realistic increase of sustainable defense production capability a manufacturing firm can achieve in the 24 month period following a declared national emergency. Report achievable increase in defense production at the end of 6 months, 12 months and 24 months in the mobilization capability section of Part II of the questionnaire. Non-Defense production limited to 25 percent or less of peacetime levels. Government financial assistance and prioritization of construction materials and outfitting equipment is available. Your existing manufacturing buildings may be enlarged, new buildings constructed or existing buildings currently used by you for non-manufacturing purposes may be converted into manufacturing facilities, and plant equipment acquired. Consider critical labor skills to operate at maximum sustained production levels. Minimum defense requirement is 4X your average monthly defense production in 1985.

OFFSET AGREEMENTS—A range of industrial and commercial compensation practices which include co-production, licensed production, subcontractor production, overseas investment, technology transfer, and countertrade.

PRACTICAL CAPACITY—Sometimes referred to as engineering or design capacity, this is the greatest level of output this plant can achieve within the framework of a realistic work pattern. In estimating practical capacity, please take into account the following considerations:

1. Assume a normal product mix. If the plant is subject to considerable short run variations in product mix, you may assume that the current pattern of production is normal unless it is unusually different because of a unique situation.
2. Consider only the machinery and equipment in place and ready to operate. Do not consider facilities which have been inoperative for a long period of time and, therefore, require extensive reconditioning before they can be made operative.
3. Take into account the additional downtime for maintenance, repair, or clean-up which would be required as you move from current operations to full capacity.
4. Do not consider overtime pay, added costs for materials, or other costs to be limiting factors in setting capacity.
5. Although it may be possible to expand plant output by using productive facilities outside of the plant, such as by contracting out subassembly work, do not assume the use of such outside facilities in greater proportion than has been characteristic of your operations.

PRODUCTION WORKERS—Persons, up through the line supervisor level, engaged in fabricating, processing, assembling, inspecting, receiving, storing handling, packing, warehousing, or shipping investment castings. In addition, persons engaged in supporting activities such as maintenance, repair, product development, auxiliary production for your firm's own use, record keeping, and other services closely associated with production operations at your firm. Employees above the working supervisor level are excluded from this item.

SCIENTISTS AND ENGINEERS—Persons engaged in research and development work or production operations that have at least a four-year college education in the physical sciences or engineering.

SHIPMENTS—Report dollar value of domestically produced castings shipped from your plant during the reporting period for each category specified for questions 4, 5, and 6 in Part I. Report shipments for defense consumption separate from non-defense. Such shipments should exclude shipments of products produced by other manufacturers for resale under your brand name. Do not adjust for returned shipments. The defense portion of your business may be identified by those purchase orders bearing a DO or DX rating and/or a contract number from the Department of Defense, NRC, CIA, FAA, or NASA, as well as the orders of your customers whom you could identify as producing products for defense purposes, and items tested and certified to military specifications shipped to qualified distributors.

SINGLE SOURCE—An item currently being purchased from one source; other sources may be available, however, they may not be qualified or were not considered.

SOLE SOURCE—An item being purchased from one source, and no other production capability exists.

SURGE PRODUCTION CAPABILITY—The maximum sustainable level of defense production that can be achieved within an existing establishment by the end of the 6 month period immediately following surge day while maintaining non-defense deliveries. Report achievable defense production quantities at the end of 3 months and 6 months in the surge capability section of Part II of the questionnaire. Procurement actions for additional materials to sustain surge production levels will be initiated on surge day. Existing idle equipment may be activated as is, repaired, or upgraded and brought into service, or used equipment may be purchased and installed if possible within the 6 month time frame. Labor may be hired and trained in numbers sufficient to operate around the clock and week-ends allowing for necessary equipment maintenance and downtime. Minimum defense requirement is 2X your average monthly defense production in 1985.

UNITED STATES—The term "United States" includes the fifty States, Puerto Rico, the District of Columbia, and the Virgin Islands.

PART I - FIRM IDENTIFICATION

1. Name and address of your firm or corporate division.

____

____

____

If your firm is wholly or partly owned by another firm, indicate the name and address of the parent firm and extent of ownership.

____

____

____

2. If your firm did not produce investment castings in the United States during the period January, 1981 to the present, check here ( ), then sign the certification at the end of this questionnaire and promptly return to the U.S. Department of Commerce.

3. Identify the location of your investment casting manufacturing establishment(s) in the United States.

	Locality	State	Zip Code
(a)			
(b)			
(c)			
(d)			

4. Enter total Non-Defense shipments of castings (all manufacturing establishments). See definition of shipments.

(In thousands of dollars)

	1981	1982	1983	1984	1985
o Investment					
o Die					
o Sand					
o Permanent Mold					
o Other (specify)					

5. Enter total Defense shipments of castings (all manufacturing establishments). See definition of shipments.

	1981	1982	1983	1984	1985
	(In thousands of dollars)				
o Investment	____	____	____	____	____
o Die	____	____	____	____	____
o Sand	____	____	____	____	____
o Permanent Mold	____	____	____	____	____
o Other (specify)	____	____	____	____	____

6. During the three year period 1983 thru 1985, estimate the total dollar value of your investment casting shipments for the following military product areas.

	Army	Navy	Air Force	Other Govt
	(In thousands of dollars)			
o Gas Turbine Engines Blades and Vanes	____	____	____	____
Other	____	____	____	____
o Aircraft Airframes	____	____	____	____
o Aircraft, Other	____	____	____	____
o Automotive	____	____	____	____
o Electronics	____	____	____	____
o Tanks	____	____	____	____
o Missiles	____	____	____	____
o Ammunition	____	____	____	____
o Weapons, other	____	____	____	____
o Other (specify)	____	____	____	____

7. Identify all military systems for which you partially or fully supply investment castings. (e.g., TOW missile, M1 Tank)

____

____

8. List your top five Non-Defense markets/product areas.

____

____

PART II - PEACETIME CAPACITY, SURGE AND MOBILIZATION CAPABILITIES

INSTRUCTIONS

- o Complete Part II for each establishment that manufactures investment castings.
- o Report calendar year data, unless otherwise specified.
- o If information is not readily available from your records in exactly the form requested, furnish estimates and designate by the letter "E".
- o Do not leave questions unanswered. Enter "none" where appropriate.

ESTABLISHMENT IDENTIFICATION

__________ (Locality) __________ (State) __________ (Zip Code)

PEACETIME CAPACITY

1. What is this establishment's investment casting production capability expressed in size range?

   pounds/ounces ________ to ________

   linear dimension ________ to ________

2. What is your annual practical capacity for producing investment castings? (See definition of practical capacity.)

Size Range (lbs)	# of castings
under 1 lb	________
1 - 5 lbs	________
6 - 10 lbs	________
11 - 20 lbs	________
21 - 50 lbs	________
over 50 lbs	________
Total	

   Enter below factors which would increase/decrease fiqures given above. (e.g. material, shape, tolerances)

   ____

   ____

   ____

3. What was this establishment's practical capacity utilization rate in percent during the last six months of 1985?

   Practical Capacity Utilization ____%

   How long would it take to reach practical capacity from the rate indicated? (in weeks)

   __________weeks

4. Enter workforce shift information below.

Operation	Average shifts Last Six Months, 1985 # shifts	man hours/ shift	days/wk	Number shifts if at practical capacity # shifts	man hours/ shift	days/wk
Die Tooling	______	______	______	______	______	______
Pattern Production /Assembly	______	______	______	______	______	______
Shell Forming	______	______	______	______	______	______
Casting/Melt	______	______	______	______	______	______
Finishing	______	______	______	______	______	______
Inspection	______	______	______	______	______	______
Other	______	______	______	______	______	______

5. Briefly discuss the convertibility of your non-defense production operations to defense production and the problems that might arise in the conversion.

____

____

____

6. During 1985, what was your average leadtime (in weeks) for:

Non-Defense Orders ________weeks Defense Orders ________weeks

Regarding your longest leadtime defense items, list the investment casting, the defense system it supports, the average leadtime during 1985, and describe how that leadtime could be significantly shortened.

Casting Product	Defense System	Average Leadtime	How to Shorten Leadtime
______	______	______	______________________
______	______	______	______________________
______	______	______	______________________
______	______	______	______________________
______	______	______	______________________
______	______	______	______________________
______	______	______	______________________

SURGE CAPABILITY

1. What is your investment casting surge capability? (See definitions of surge capability and shipments. Assume 1985's defense product mix.)

Size Range	1985's average monthly defense production rate (# of castings)	Surge rate at 3 months (# of castings)	Surge rate at 6 months (# of castings)
under 1 lb	______	______	______
1 - 5 lbs	______	______	______
6 - 10 lbs	______	______	______
11 - 20 lbs	______	______	______
21 - 50 lbs	______	______	______
over 50 lbs	______	______	______

2. List and rank the bottlenecks you envision would be encountered during a surge and the time and cost to correct. Refer to definition of BOTTLENECKS. Rank bottlenecks in order of occurrence. If the answer is "none", please indicate.

Operation	Bottlenecks	Rank	Time and Cost to Correct
Die Tooling	______	______	______
Pattern Production /Assembly	______	______	______
Shell Forming	______	______	______
Casting/Melt	______	______	______
Finishing	______	______	______
Inspection	______	______	______
Other areas			
Raw Material Inventory	______	______	______
Government Regulations	______	______	______
Other (specify)	______	______	______

3. What can the government do to help reduce or eliminate bottlenecks?

____

____

____

____

____

MOBILIZATION CAPABILITY

1. What is your mobilization capability for investment castings? (See definitions of mobilization capability and shipments. Assume 1985's defense product mix.)

		(# of castings)		
Size Range	1985's average monthly defense production rate	Mobilization rate at 6 months	Mobilization rate at 12 months	Mobilization rate at 24 months
under 1 lb	______	______	______	______
1 - 5 lbs	______	______	______	______
6 - 10 lbs	______	______	______	______
11 - 20 lbs	______	______	______	______
21 - 50 lbs	______	______	______	______
over 50 lbs	______	______	______	______

2. List and rank the bottlenecks you envision would be encountered during a mobilization and the time and cost to correct. Refer to definition of BOTTLENECKS. Rank bottlenecks in order of occurrence. If the answer is "none", please indicate.

Operation	Bottlenecks	Rank	Time and Cost to correct
Die Tooling	______	______	______
Pattern Production /Assembly	______	______	______
Shell Forming	______	______	______
Casting/Melt	______	______	______
Finishing	______	______	______
Inspection	______	______	______
Other areas			
Raw Material Inventory	______	______	______
Government Regulations	______	______	______
Other (specify)	______	______	______

3. What can the government do to help reduce or eliminate bottlenecks?

______

______

______

______

______

PART III - EMPLOYMENT, RESEARCH AND DEVELOPMENT, INVESTMENT AND INVENTORIES.

INSTRUCTIONS

- o Complete Part III for each establishment that manufactures investment castings.
- o If information is not readily available from your records in exactly the form requested, furnish estimates and designate by the letter "E".
- o Enter "none" where appropriate.

ESTABLISHMENT IDENTIFICATION

__________ (Locality) __________ (State) __________ (Zip Code)

1. Investment: Enter expenditures for new plant, machinery, and equipment from 1981 through 1985 as requested below. Enter any government investment expenditures at your establishment separately.

Private Investment Expenditures (in thousands of dollars)

	1981	1982	1983	1984	1985
Plant	___	___	___	___	___
Machinery and Equipment	___	___	___	___	___
Total:					

Government Investment Expenditures (in thousands of dollars)

	1981	1982	1983	1984	1985
Plant	___	___	___	___	___
Machinery and Equipment	___	___	___	___	___
Total:					

2. Planned expansion: Enter percentage increase(+)/decrease(-) in practical capacity planned for in the next five years.

_____% Reason for increase/decrease ____________________

3. What is the average age of your capital equipment?

Die tooling	___	Pattern Production /Assembly	___
Shell forming	___		
Finishing	___	Inspection	___
Casting/Melt	___	Other (specify)	___

4. Enter the square footage used for the following operations.

Die Tooling	________	Finishing	________
Pattern Production /Assembly	________	Inspection	________
Shell Forming	________	Other (specify)	________
Casting/Melt	________		

5. Place a check mark next to those test procedures for which you have in-house capabilities to perform.

[ ] Magnetic particle
[ ] Fluorescent penetrant
[ ] Dye penetrant
[ ] Radiographic

6. Estimate the percent by Grade, as established by radiographic inspection, of your 1985 investment casting production.

Grade A ______%
Grade D ______%
Grade B ______%
Grade E ______%
Grade C ______%

7. Has this establishment been approved/qualified to any of the following military inspection standards?

[ ] Mil-I-45208
[ ] Mil-Q-9858
[ ] Mil-C-45662

8. In 1985, what was the percent (in value) of total materials used in your investment casting production for:

____ Aluminum alloys	____ Nickel base alloys	____ Copper
____ Carbon/low alloy steels	____ Titanium	____ Copper base alloys
____ Ductile iron	____ 300 series stainless	____ Vacuum cast superalloys
____ Silicon iron	____ Tool steels	____ Magnesium alloys
____ 400 series stainless	____ Cobalt steels	____ Other (specify)

Total: 100 %

9. Employment: Enter the number of employees from 1981 through 1985 as requested below. (See definition of Scientists and Engineers, and Production Workers)

	1981	1982	1983	1984	1985
Scientists and Engineers	____	____	____	____	____
Production Workers	____	____	____	____	____
Administration and Others	____	____	____	____	____
Total:					

Critical Occupations: List below. (See definition of Critical Occupations)

Job Title	Number Employed	Training Period (in months)

10. Research and Development: Enter research and development expenditures from 1981 through 1985 as requested below. Enter any Government funded expenditures separately.

Private Funded Research and Development Expenditures
(in thousands of dollars)

	1981	1982	1983	1984	1985
On Materials	____	____	____	____	____
On Processes	____	____	____	____	____
Other	____	____	____	____	____
Total:					

Government Funded Research and Development Expenditures
(in thousands of dollars)

	1981	1982	1983	1984	1985
On Materials	____	____	____	____	____
On Processes	____	____	____	____	____
Other	____	____	____	____	____
Total:					

11. In which of the following areas do you consider the application of new technologies to be most critical? Number from one to seven.

[ ] Die Tooling

[ ] Pattern production/Assembly

[ ] Shell forming

[ ] Casting/Melt

[ ] Finishing

[ ] Inspection

[ ] Other ________________ (specify)

List and rank new technologies you would be most interested in acquiring.

____

____

____

12. Inventory: In the space provided below, briefly discuss your inventory policies for materials and supplies. Cite the average number of days supply you normally have in house for your materials and supplies.

____

____

____

13. Have you in the past five years experienced shortages or extended leadtimes in obtaining any material or supply, machinery, equipment, or additional labor that forced you to modify or curtail your operations?

__________yes __________no

If yes, list below. Identify the nature and duration of the problem on your operation and the action you took to resolve the situation.

____

____

____

14. What percent of your work did you subcontract out/off load in the past five years?

1981	1982	1983	1984	1985
____	____	____	____	____

Specify the operations most frequently subcontracted.

____

____

15. Do you assemble components/castings into subassemblies, or larger castings?

__________yes __________no

If yes, indicate percent of direct labor hours utilized in assembly, and briefly describe the types of products assembled.

____

____

____

16. a.) Are you considered a sole source or single source producer for any defense related casting, assembly, or component?

__________yes __________no

If yes, specify and provide the basis for such a position. (See definitions of sole and single source.)

____

____

____

b.) Do you have any sole source or single source suppliers for manufacturing equipment/parts/components/materials?

__________yes __________no

If yes, specify the equipment/part/component/material, the name of the supplier, and how the loss of that supplier would effect your operations.

____

____

____

____

PART IV - FOREIGN RELATIONSHIPS / FOREIGN SOURCING
(Part IV may be completed for your firm as a whole)

1. Enter the location and primary activity of any establishment outside the United States your firm wholly or partly owns or controls or is affiliated with or has license agreements with that manufactures investment castings.

Name	Country	Primary Activity

2. If any of the foreign establishments you listed above are integrated with your U.S. operations on a normal basis, please briefly specify the nature of that integration in the space provided below.

____

____

____

____

3. If the foreign establishments that you interact with suddenly ceased operations for an indefinite period, what adjustments would you need to make in your U.S. operations to counteract this interruption?

____

____

____

____

4. Complete the following table addressing which foreign made manufacturing equipment/parts/components/materials you use in your manufacturing operations. Use the following coded reasons why a foreign source is used in completing the table:

   A. No known domestic source
   B. Domestic source not available or inadequate
   C. Offset Agreement
   D. Lower cost
   E. Quicker delivery
   F. Better quality
   G. Other (specify)

Item	Country of Origin	Are spare parts/maintenance available only from a foreign source?	Reason why foreign source

5. If the foreign sourced items identified in question 4 are lost, what is your contingency plan (i.e. qualified domestic source, alternate material) and does this impact your ability to surge or mobilize?

____

____

____

____

____

____

6. In recent years, have offset agreements affected your firm?

__________yes __________no

If yes, how? ____

____

____

____

____

CERTIFICATION

The undersigned certifies that the information herein supplied in response to this questionnaire is complete and correct. The U.S. Code, title 18 (Crimes and Criminal Procedure), Section 1001, makes it a criminal offense to willfully make a false statement or representation to any department or agency of the Untied States as to any matter within its jurisdiction.

(Date)	(Signature of Authorized Official)
Area Code and Telephone Number	(Type or Print Name and Title of Authorized Official)
Area Code and Telephone Number	(Type or Print Name and Title of Person to Contact Regarding this Report

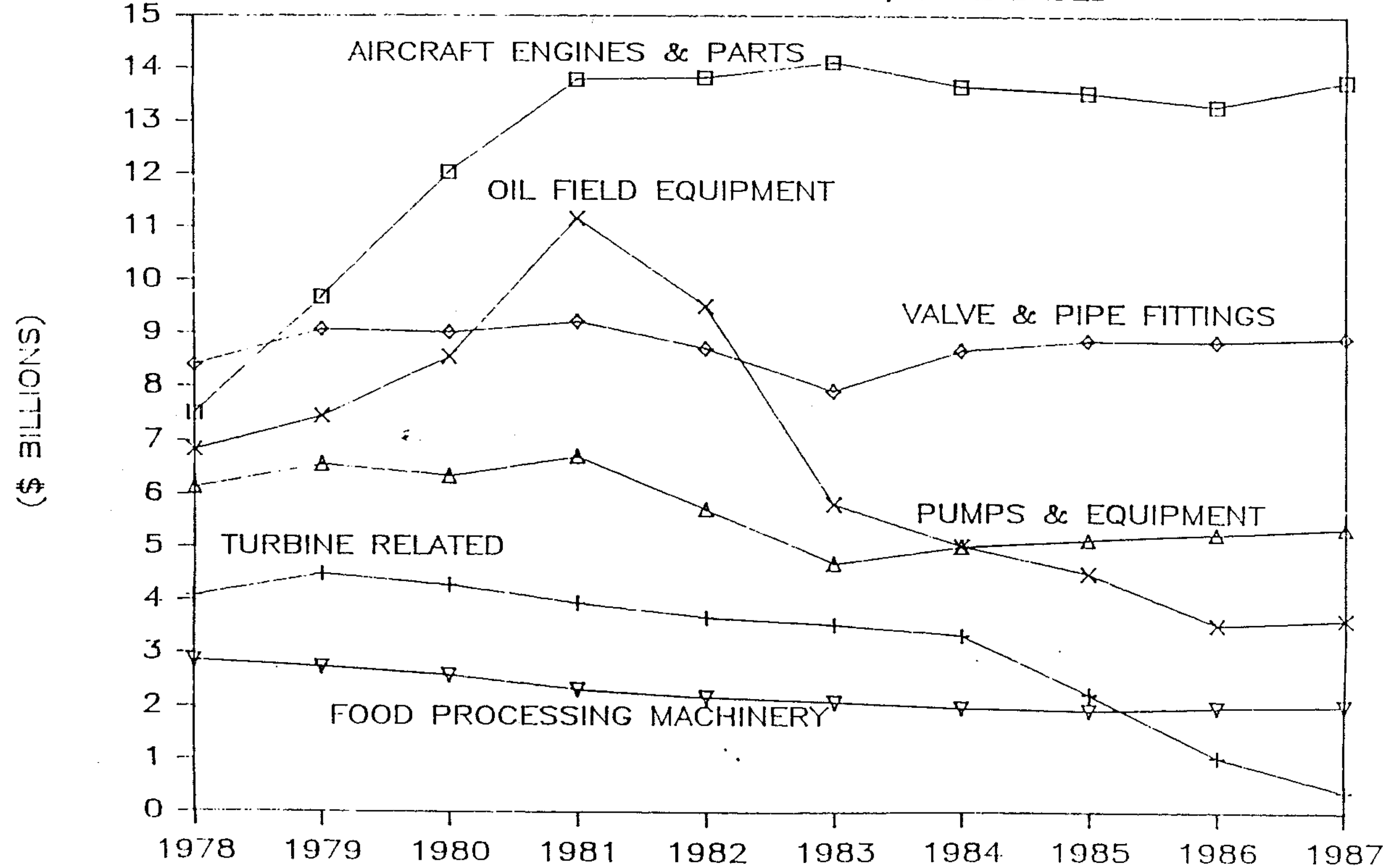
Comments: If you wish to add anything not covered in the questionnaire that, in your judgment might be useful to, or that should be brought to the attention of this assessment, please use the space below. Topics of special interest include international competition, government regulations, technology advancement in machinery and equipment and/or material formulations, and possibilities for improving defense productivity and costs.

APPENDIX E

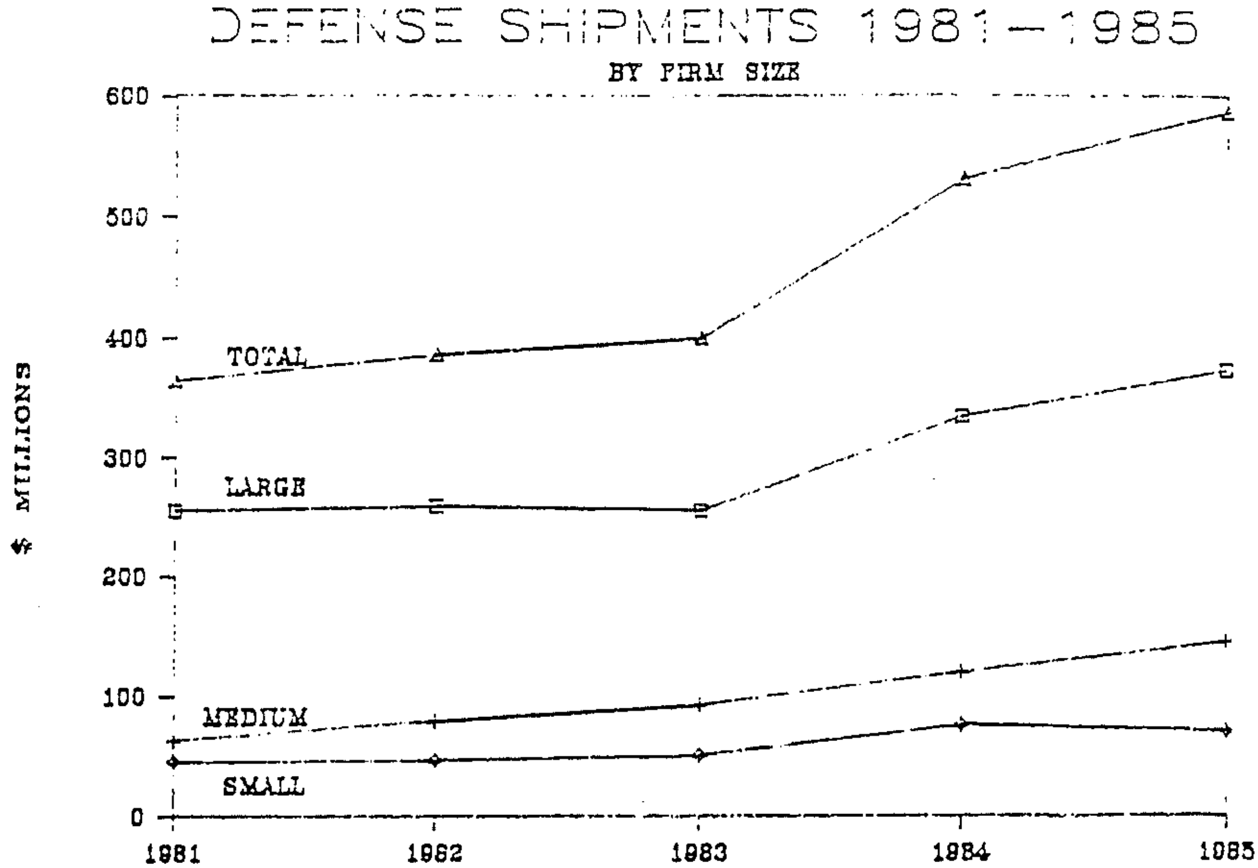
Selected Statistical Tables and Graphs

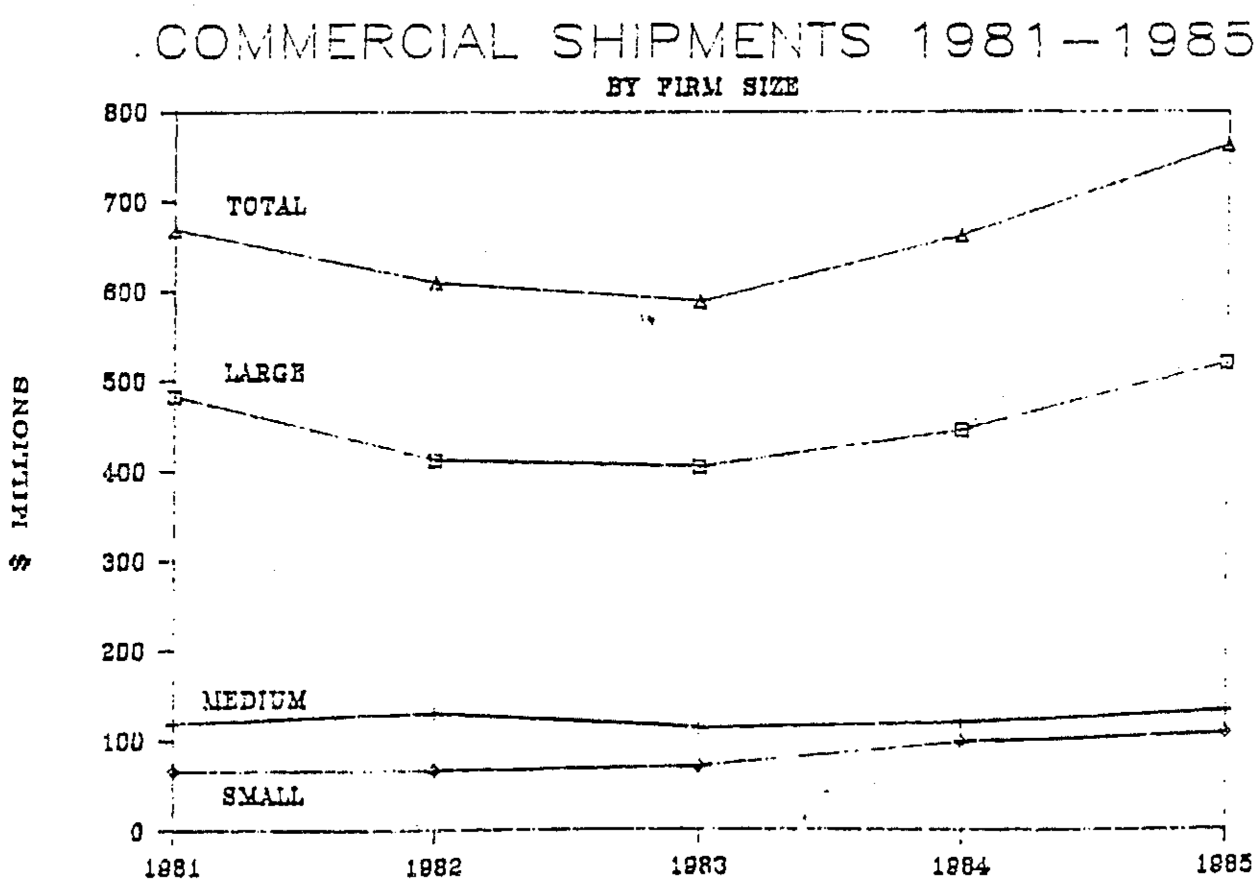
SELECTED END—MARKETS: 1978—87

PRODUCT SHIPMENT VALUES, 1982 BASED



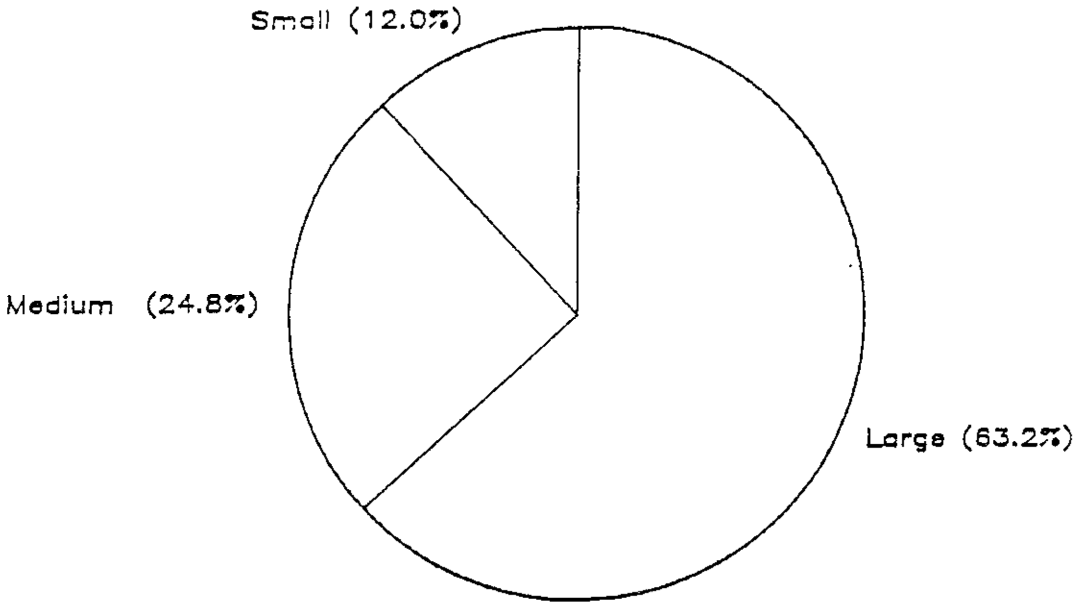
Source: Bureau of the Census



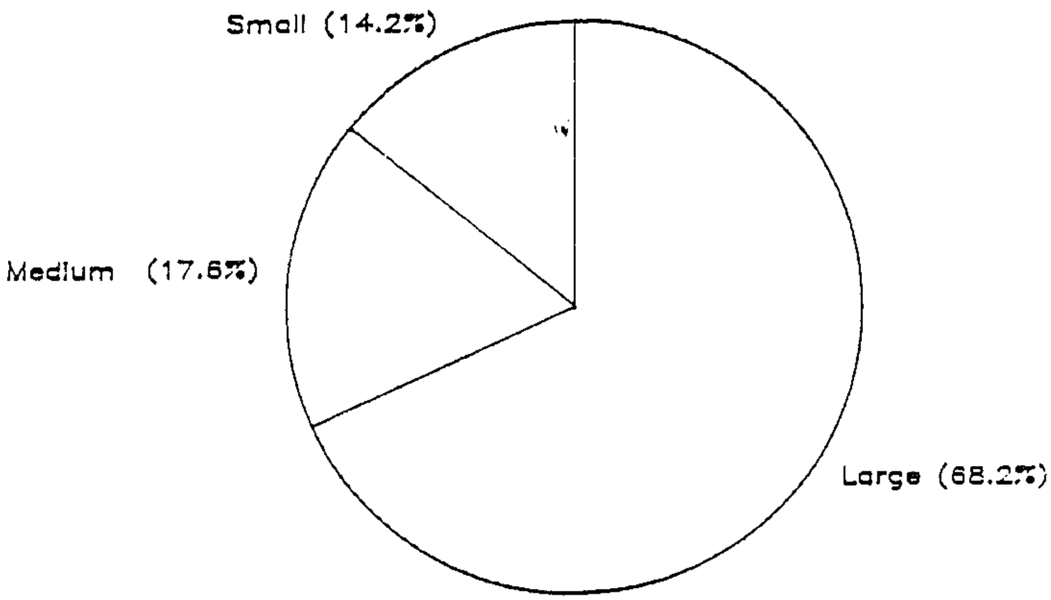


Source: DOC/OIRA Industry Survey

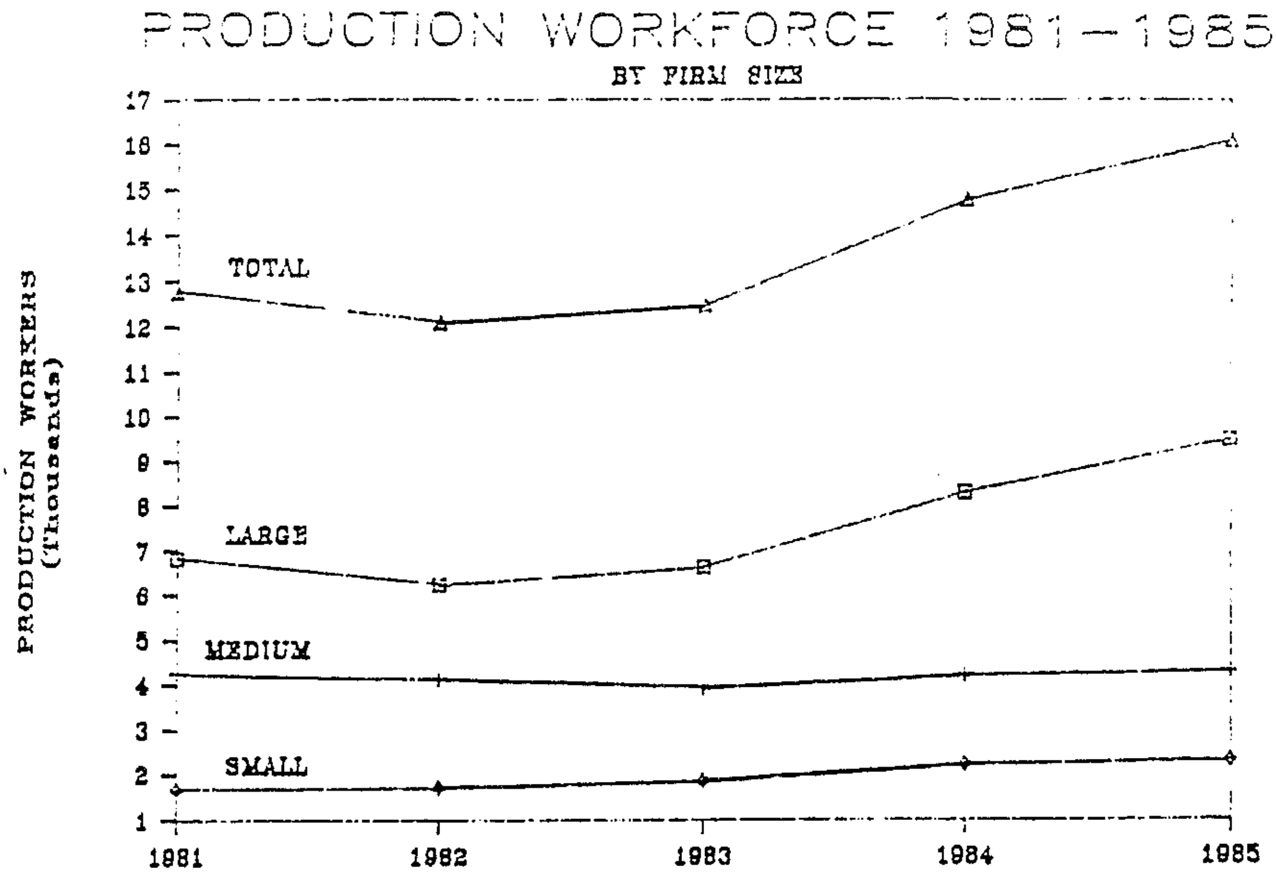
DEFENSE SHIPMENTS
1985 SHARE BY FIRM SIZE

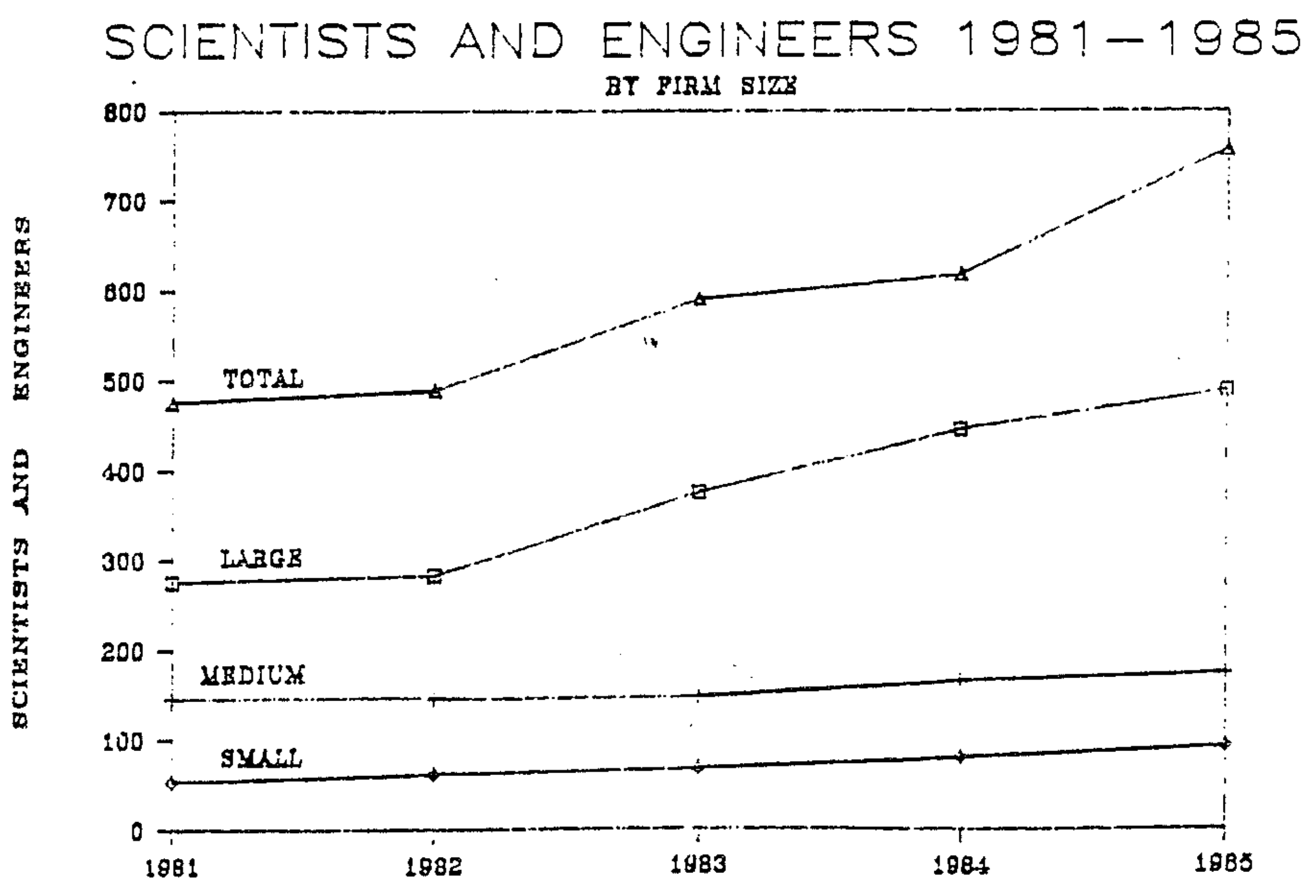


COMMERCIAL SHIPMENTS
1985 SHARE BY FIRM SIZE



Source: DOC/CIRA Industry Survey





Source: DOC/OIRA Industry Survey

COST OF MATERIALS
AS A PERCENTAGE OF SHIPMENTS VALUE: 1978-1985

Industry	1978	1979	1980	1981	1982	1983	1984	1985
All Manufacturing	57.6%	57.8%	59.0%	59.2%	57.7%	57.0%	57.2%	56.0%
Steel Investment Castings	36.4%	39.4%	39.2%	37.3%	35.5%	37.8%	37.5%	37.8%
Ferrous Foundries	44.0%	45.0%	43.8%	47.0%	43.0%	44.7%	42.9%	43.5%
Non-Ferrous Foundries	49.2%	50.3%	48.9%	47.9%	45.9%	46.7%	48.0%	47.6%
Forgings and Stampings	52.1%	52.5%	51.3%	51.2%	50.6%	50.5%	52.2%	52.2%

WAGES PAID
AS A PERCENTAGE OF VALUE ADDED: 1978-1985

Industry	1978	1979	1980	1981	1982	1983	1984	1985
All Manufacturing	26.8%	25.8%	25.6%	25.3%	24.8%	24.1%	23.6%	23.6%
Steel Investment Castings	33.6%	32.3%	30.5%	29.2%	31.0%	32.4%	32.3%	33.9%
Ferrous Foundries	42.9%	42.9%	41.8%	44.0%	41.9%	43.6%	40.8%	42.3%
Non-Ferrous Foundries	41.0%	40.1%	39.3%	39.7%	40.8%	38.1%	38.5%	40.5%
Forgings and Stampings	37.9%	37.1%	37.1%	36.7%	37.5%	36.3%	37.4%	39.6%

CAPITAL INVESTMENT
PER PRODUCTION WORKER: 1978-1985

($ per worker per annum)

Industry	1978	1979	1980	1981	1982	1983	1984	1985
All Manufacturing	3,880	4,233	5,044	5,806	6,013	5,101	5,976	6,539
Steel Investment Castings	1,063	2,134	2,690	1,706	2,611	1,903	1,866	3,645
Ferrous Foundries	3,971	4,137	4,937	5,492	3,894	2,719	3,212	4,096
Non-Ferrous Foundries	2,943	3,724	3,246	3,263	2,837	2,632	4,625	3,850
Forgings and Stampings	3,007	3,267	4,665	6,230	5,144	3,060	4,264	6,050

VALUE ADDED
PER PRODUCTION WORKER: 1978-1985

($ per worker per annum)

Industry	1978	1979	1980	1981	1982	1983	1984	1985
All Manufacturing	46,203	51,416	55,671	61,841	66,458	72,322	79,153	82,085
Steel Investment Castings	34,242	39,202	43,929	49,412	50,452	52,124	54,306	56,631
Ferrous Foundries	35,854	37,709	40,066	41,054	43,273	46,597	54,598	54,549
Non-Ferrous Foundries	30,662	33,091	36,204	39,446	40,496	46,040	49,358	47,931
Forgings and Stampings	40,394	43,044	44,279	51,133	52,857	59,311	61,959	62,062

Source: Bureau of the Census

W O R K F O R C E : 1 9 7 8 - 1 9 8 5

ALL EMPLOYEES

(in thousands)

Industry	1978	1979	1980	1981	1982	1983	1984	1985
All Manufacturing	20,502	21,040	20,647	20,264	19,094	18,720	19,123	18,791
Steel Investment Castings	12	15	16	16	15	17	17	19
Ferrous Foundries	236	244	220	208	157	138	147	136
Non-Ferrous Foundries	86	94	88	84	75	74	83	83
Forgings and Stampings	298	295	275	262	236	240	269	269

Source: Bureau of the Census

PRODUCTION WORKERS

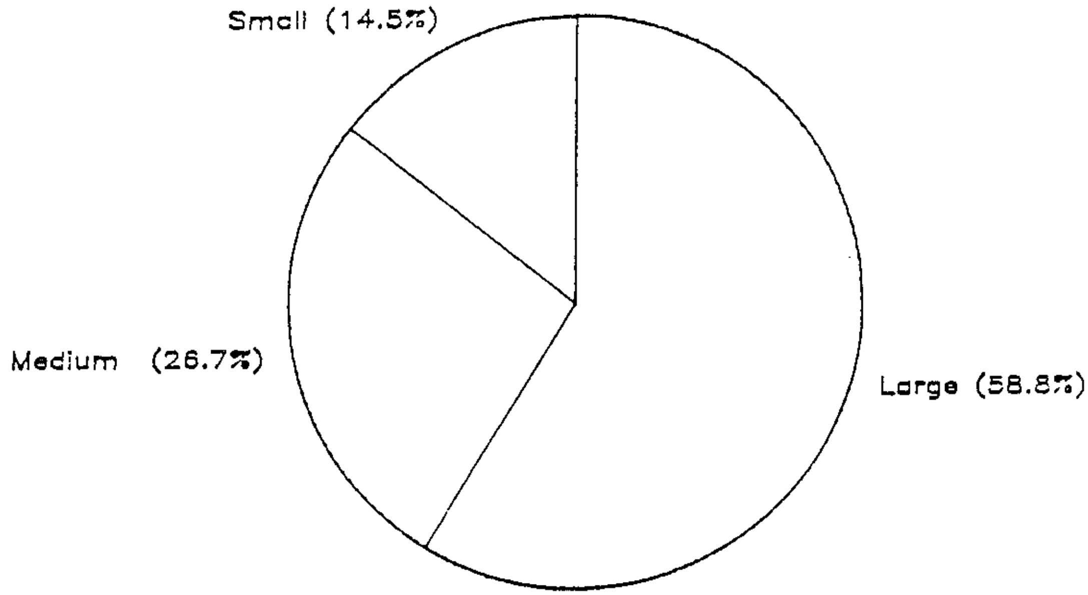
(in thousands)

Industry	1978	1979	1980	1981	1982	1983	1984	1985
All Manufacturing	14,229	14,538	13,900	13,543	12,401	12,203	12,573	12,171
Steel Investment Castings	10	12	13	12	13	11	13	14
Ferrous Foundries	196	202	178	168	124	109	119	109
Non-Ferrous Foundries	72	79	72	70	61	60	67	67
Forgings and Stampings	245	242	223	211	184	190	215	215

Source: Bureau of the Census

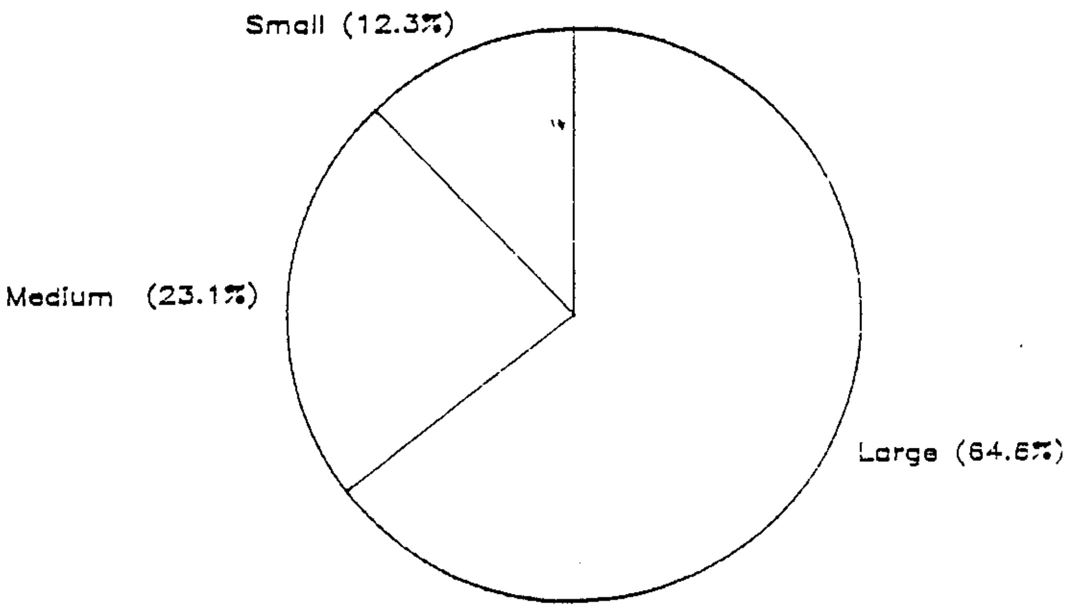
TOTAL PRODUCTION WORKFORCE

1985 SHARE BY FIRM SIZE

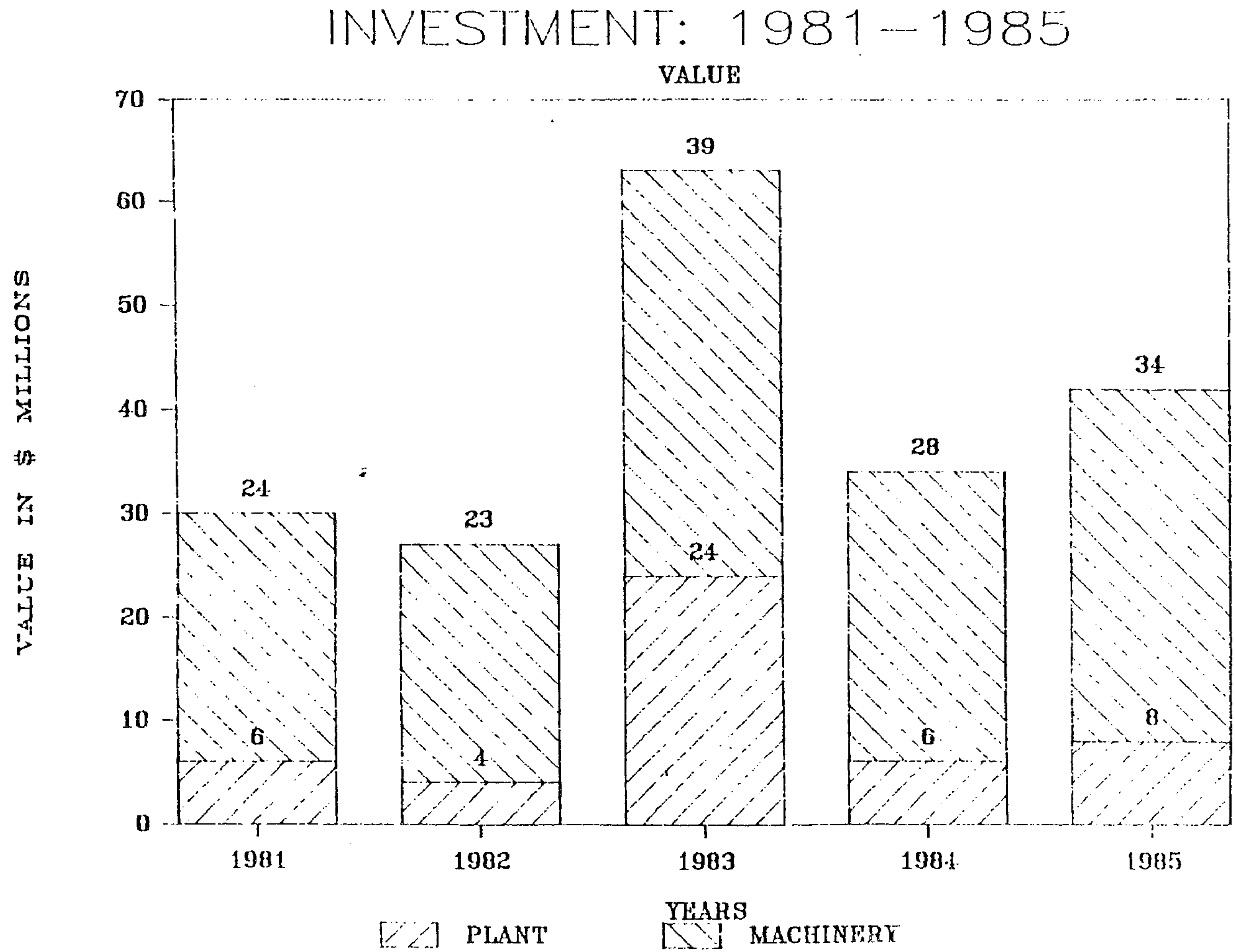


TOTAL SCIENTISTS AND ENGINEERS

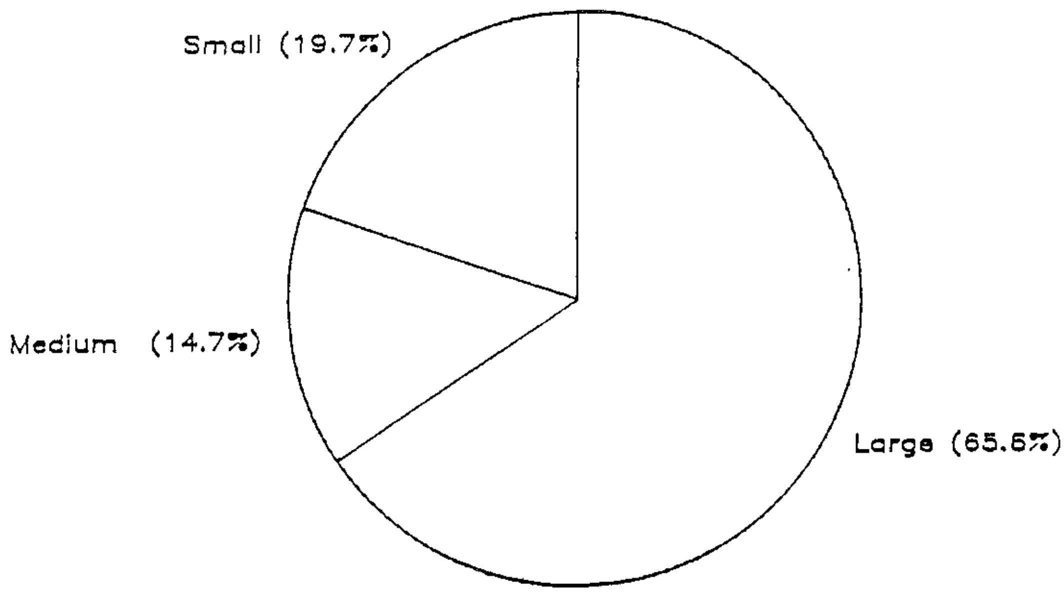
1985 SHARE BY FIRM SIZE



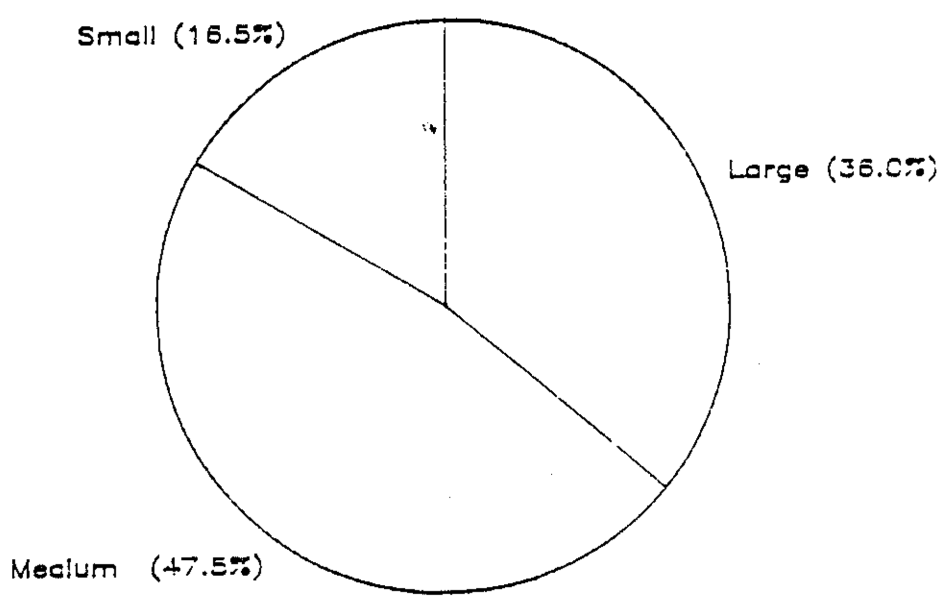
Source: DOC/OIRA Industry Survey


INVESTMENT: 1981 – 1985
VALUE
VALUE IN $ MILLIONS
70
60
50
40
30
20
10
0
24
6
23
4
39
24
28
6
34
8
1981
1982
1983
1984
1985
YEARS
PLANT
MACHINERY

TOTAL INVESTMENT
1985 SHARE BY FIRM SIZE



RESEARCH AND DEVELOPMENT
1985 SHARE BY FIRM SIZE



Source: DCC/OIRA Industry Survey