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REPORT OF INVESTIGATIONS CONCERNING NUMERICAL CONTROLLED MACHINING OF AEROSPACE PARTS

October, 1980

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REPORT OF INVESTIGATIONS CONCERNING NUMERICAL CONTROLLED MACHINING OF AEROSPACE PARTS

October, 1980

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The responsibility for the content of this report is the consultant's alone, and the conclusions reached herein do not necessarily reflect the opinions of those who assisted during the course of this investigation or the Federal and Provincial governments which funded the study.

REPORT OF INVESTIGATIONS CONCERNING NUMERICAL CONTROLLED MACHINING OF AEROSPACE PARTS

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I. INTRODUCTION

Bacon, Donaldson and Associates Limited, has been engaged to undertake a study concerning numerical controlled machining of parts for the aerospace industry, with particular reference to the parameters necessary for machine shops located in B.C. to obtain some of this work on a sub-contract basis.

The intent of this study is to provide information on the requirements of the aerospace industry concerning sub-contract numerical-controlled (N.C.) machining, the existing market and market prospects for such work, and also to provide information on the existing and planned machine-shop facilities in B.C. which are presently, or may in future be, directed toward aerospace machining.

This study has used market and statistical information provided by the Lockheed "DIALOG" data base, Statistics Canada, and other sources. Background and technical information has been obtained from various textbooks and trade journal publications. In addition, personal and telephone interviews have been held with representatives of a cross-section of U.S. and Canadian companies, of various B.C. suppliers of machine tools, and of all B.C. machine shops which are known to possess N.C. machine tools.

II. N.C. MACHINE TOOLS - BACKGROUND INFORMATION

A) Metal Removing Machine Tools - General Information

There is a great variety of different machine tools in a bewildering array of configurations which are used for metal removal. However, most of these types may be divided into three broad categories depending upon the relative motion of the tool and the workpiece.

When the workpiece is rotated relatively rapidly and the cutting tool does not rotate, but moves only in a plane at relatively low speeds, the machine tool is called either a lathe or a vertical boring mill. Machining operations performed by lathes and vertical boring mills include turning, drilling, boring, threading, and tapping.

When the cutting tool is rotated rapidly and the workpiece is either held stationary or moved only relatively slowly during the metal cutting operation, the machine tool may be called variously a drilling machine, a contour mill, or a machining center. Operations performed by such machines include drilling, boring, tapping, milling, profiling, and contouring.

In the third category, neither the tool nor the workpiece is rotated rapidly. In this case, a sharp cutting tool is drawn linearly across the workpiece. Machines of this type include shapers and planers. These less common machine tools have limited application in aerospace work and have very little popularity as N.C. machine tools. Therefore, these types of machine tools will be ignored for the balance of this report.

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N.C. MACHINE TOOLS - BACKGROUND INFORMATION (cont.)

It should be noted that grinding heads may be installed instead of conventional cutting tool holders or spindles on most configurations of machine tools, producing grinding machines of various capabilities.

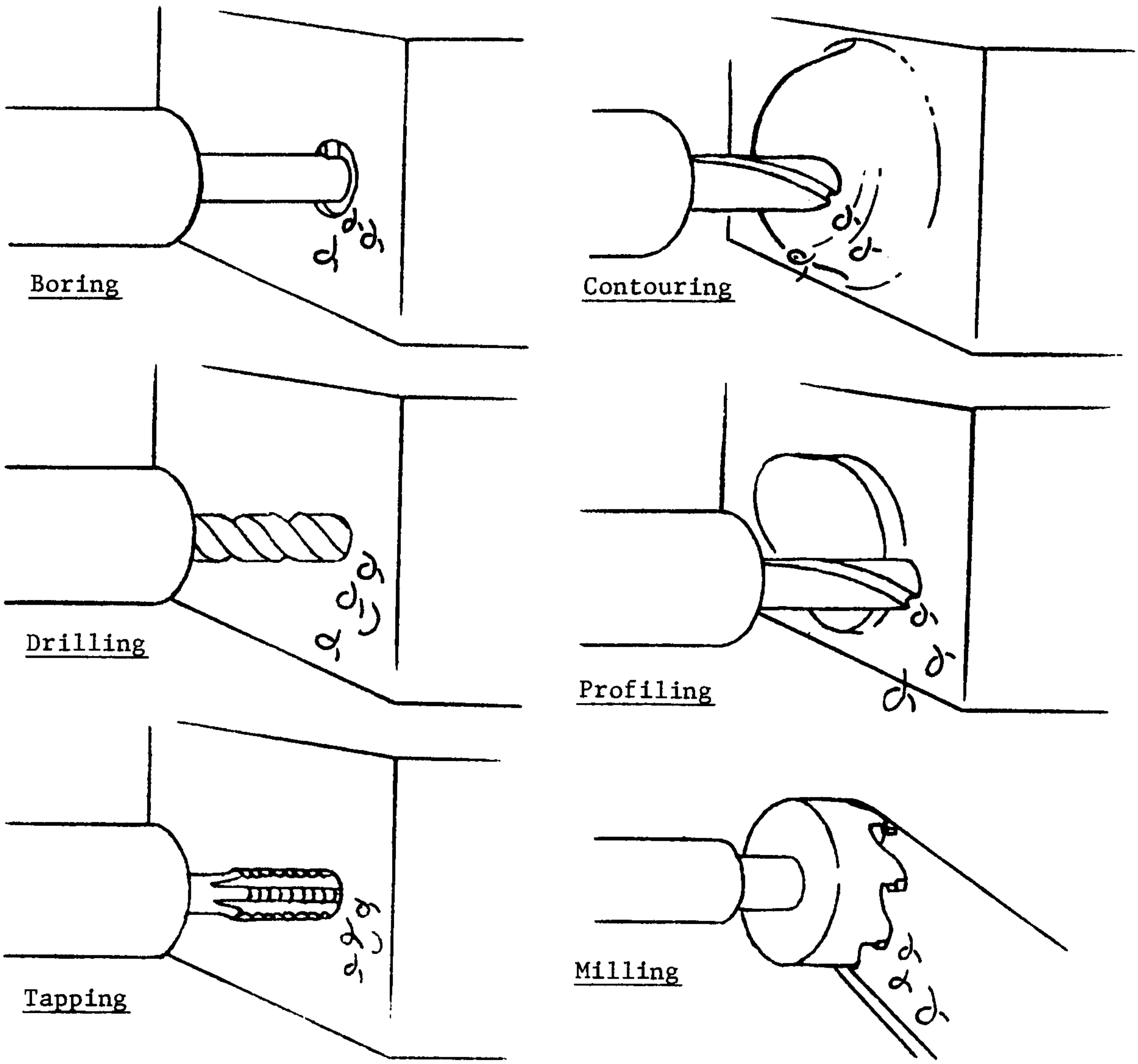

FIGURE 1 - Various Machining Operations

N.C. MACHINE TOOLS - BACKGROUND INFORMATION (cont.)

B) Numerical Control - General Information

The theory any practice involved in numerically controlled operations is very complex and cannot be covered in detail in this report. If anyone lacking knowledge in this field requires in-depth information, he should consult one of the many textbooks available, a number of which are listed in the Bibliography, Appendix IV of this report.

Briefly and simply, numerical control is defined as "control of a process through use of numbers". Two interesting features of numerical control (N.C.) as applied to machine tools are:

1. Real Time Operation - the control function is performed at a rate compatible with the operation of physical equipment or process.

2. Memory - the control of the process is accomplished with "stored knowledge" (either in the form of electronic memory storage of physical storage, such as on punched tape or pre-recorded magnetic tape). This "stored knowledge" is unaltered by human intervention after implementation.

In metal cutting operations, the cutting speed is the same for manual or N.C. machines. However, for a manually operated machine tool used for cutting complex metal configurations, the time spent actually cutting metal may be only a small fraction of the total machine time.

N.C. MACHINE TOOLS - BACKGROUND INFORMATION (cont.)

N.C. Machine tools improve productivity by reducing the time spent on non-metal cutting functions such as tool changing, tool positioning, and workpiece loading and unloading.

Perhaps more importantly, N.C. machine tools are programmed so that the cutting tool path of motion is precisely defined, so that, once a program is read by the machine, the possibility of inaccuracies caused by human error is greatly reduced. Also, there is a greatly reduced need to check part dimensions between metal cutting passes. The above two factors are considered to improve machining accuracy, to increase the repeatable accuracy between numbers of identical machined parts produced on the same machine, and to further increase productivity through reduction in the number and frequency of dimensional checks needed during the machining operation.

On complex metal configurations, before N.C., the most practical way to make numbers of such parts was to employ complex and costly fixtures, holding jigs, and mechanical templates. With N.C., the positional control previously provided by such complex mechanical devices is provided simply by entering numeric information on a typewriter-style keyboard. This yields a great reduction in tooling costs.

C) Numerical Control of Machine Motion Functions

There are two basic methods of controlling the motion of a cutting tool on an N.C. machine. In the first of these methods, the tool is programmed to move from

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one point in space to another point in space. The exact path that the tool follows in moving between these two points is not specified by the program, and may, in fact, be an irregular path. Such control is termed "point-to-point" or "positioning" control. An example of where "point-to-point" control is used is in selecting the position of a drill bit on a drilling machine or jig bore.

The other type of control is termed "contouring" control. In this case, the tool moves between points following a path which is precisely specified by the program at a velocity along this path which also may be specified by the program. An example of "contouring" control is the control of the position of the bit on a profiling machine. A machine with "contouring" control may also move tools into position by "point-to-point" control when this latter mode is selected by the program.

Each direction of linear motion or rotation along which either the workpiece or the tool is moved is termed a machine "axis" (in the plural - "axes").

N.C. MACHINE TOOLS - BACKGROUND INFORMATION (cont.)

The three fundamental axes of motion, C', X, and Z, which may be controlled on N.C. lathes, are illustrated in Figure 2.

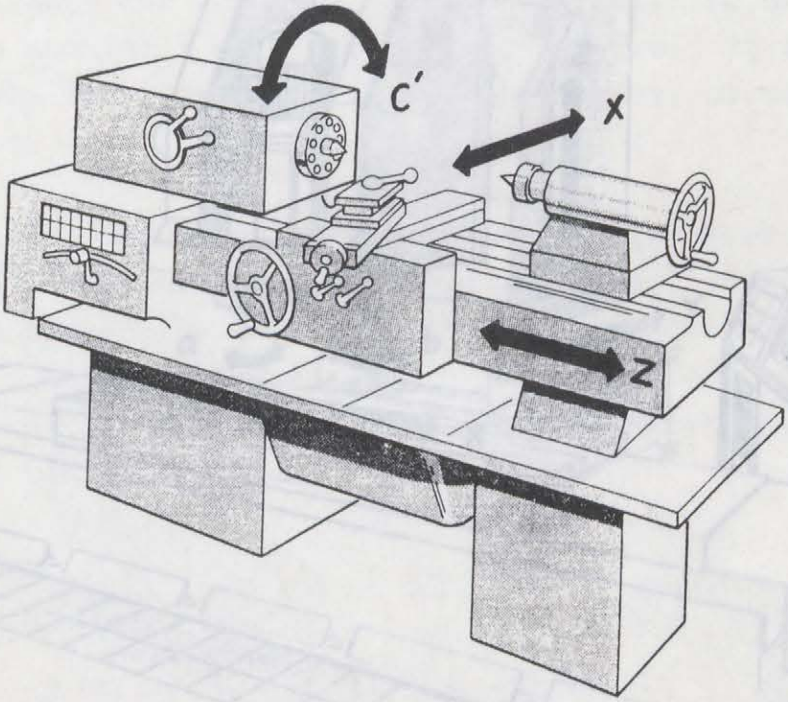

FIGURE 2 - Fundamental Axes of Motion on a Lathe

The five fundamental axes of motion, X, Y, Z, a, and b, which may be controlled on a drilling, milling, or profiling machine, are illustrated in Figure 3.

N.C. MACHINE TOOLS - BACKGROUND INFORMATION (cont.)

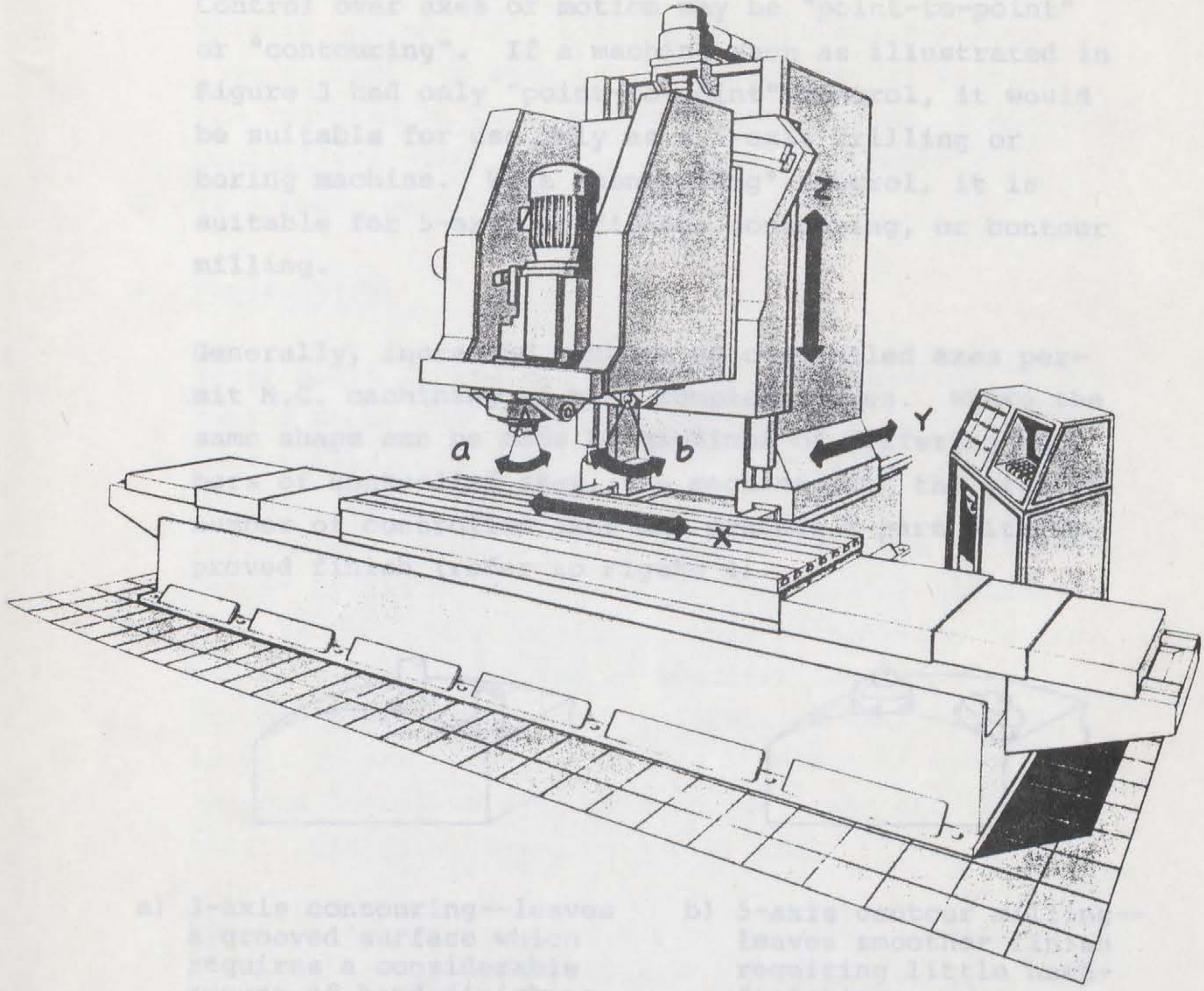

FIGURE 3 - Fundamental Axes of Motion on a Drilling, Milling or Profiling Machine

N.C. machines are generally described in terms of the number of axes controlled. For example, the profiling machine shown in Figure 3 is a "five-axis" machine. However, if the machine did not have the two rotation axes, "a" and "b", it would be called a "three-axis" machine.

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N.C. MACHINE TOOLS - BACKGROUND INFORMATION (cont.)

Control over axes of motion may be "point-to-point" or "contouring". If a machine such as illustrated in Figure 3 had only "point-to-point" control, it would be suitable for use only as a 5-axis drilling or boring machine. With "contouring" control, it is suitable for 5-axis profiling, contouring, or contour milling.

Generally, increased numbers of controlled axes permit N.C. machining of more complex shapes. Where the same shape can be made by machines of differing numbers of controlled axes, the machine with the greater number of controlled axes may produce a part with improved finish (refer to Figure 4).

a) 3-axis contouring--leaves a grooved surface which requires a considerable amount of hand-finishing.

b) 5-axis contour milling--leaves smoother finish requiring little hand-finishing.

FIGURE 4 - Comparison of 3-axis Contouring with 5-axis Contour Milling

It should be noted that sometimes extra control axes are added which operate in directions parallel to one of the fundamental axes of machine control. Such extra axes may provide increased flexibility for the machine tool.

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In cases where there is more than one tool holder or spindle and the tool holders or spindles may move independently of each other, extra axes of control are required to move the extra tool holder or spindle. Controllers exist which are capable of controlling up to 8 axes, each with contouring mode.

D) Programming

Programming is the process by which dimensional information about the part to be machined is translated into cutting tool position, cutting speed, direction of motion, feed rate, and sequence of passes. Then this information is placed in a format which can be "understood" by the controller of the particular machine tool in use. Most commonly, this information is provided by means of holes at specific locations on punched tape. Additional information usually contained in the program includes a number of miscellaneous functions such as turning on and off the cutting fluid flow, changing tools, etc.

Parts of simple geometry may be manually programmed directly in "machine language" (i.e. the control language understood by the machine tool).

Parts of more complex geometry are frequently first programmed with the aid of a computer in an "English-like" language, most commonly one known as "Automatically Programmed Tools", abbreviated "APT". This first step of programming translates the part geometry into tool locations, velocities, and operation sequences necessary to machine the part. Then the

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part program in the APT language is processed in a device (which may be no more than a program in a computer) known as a "post-processor" to provide the program in "machine language". The machine language program is then used to produce a punched tape (most commonly) which is then read directly by the machine tool controller. This controller then directs the machine tool in actually machining the part.

On older machine tool controllers, the tape reader unit tended to be somewhat unreliable. This led to the development of Direct Numerical Control (DNC) where the data, in machine language, is stored in a computer memory bank and fed to the machine tool electronically as needed, thus eliminating the need for punch tape and tape reader.

Older machine tool controllers had no computational capability, and were commonly called "tape directors". With the advent of small size, low cost micro-computers, it is now common to find machine tool controllers with memory and computational capability. These modern controllers are called CNC (for Computer Numerical Control) and serve to simplify programming and/or provide additional capabilities such as inch/metric conversions and storage of sub-routines used in place of repetitive programs.

Programming is generally performed away from the machine tool. Skilled personnel are needed for programming, and the skill and ingenuity of the programmer can have a significant bearing on the efficiency of utilization of the machine tool and, hence, on the cost of the finished product.

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E) N.C. Machine Tools

1. Lathes

The most common types of N.C. lathes are 2-axis, either with point-to-point or contouring control.

Some lathes have automatic tool changers, and some turret lathes have up to 4-axis control.

2. Drilling Machines and Boring Mills

These machines may have 3, 4, or 5-axis point-to-point control. They are used for drilling or boring holes, including holes at angles when more than 3 axes are provided.

3. Profiling and Contouring Mills

These machines may have 3, 4, or 5-axis contouring control. These machines may be used for profiling, contouring or milling. The greater the number of axes, the greater the complexity of geometry which can be machined without the necessity of remounting the workpiece prior to completion of machining.

Prior to the advent of N.C., profilers and contour mills had employed 3-axis servo-control* directed manually by an operator moving a stylus

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* "Servo" (short for "servo-mechanism"): A closed loop control system in which the controlled variable is mechanical position.

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along or across a mechanical template. Such machines are frequently called "copy milling machines", and many such machines of this type continue in use by the aerospace industry, in spite of the high initial cost for making mechanical templates.

4. Machining Centers

The term "machining center" is a machine designed to utilize the full capabilities of N.C. control. In its simplest form, a machining center is a profile or contour mill with a minimum of 3 contouring axis control which is equipped with an automatic tool changer, generally capable of holding 20 or more different tools. A tool change to any one of the tools in the changer can be called up by a programming instruction.

Such a machine is then capable of drilling, boring, threading, profiling, contouring, milling, etc., without remounting the workpiece or requiring attention from the machine operator.

Machining centers may be 3, 4 or 5-axis, with at least 3 axes being contouring axes. Another feature sometimes found on machining centers is two (or more) indexing work tables which permit the loading or unloading of one part while the machine is performing machining operations on a second part. This feature serves to increase actual machine utilization time.

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Machining centers are more commonplace in the current N.C. machine tool market than simple single-spindle profiling and contour mills requiring manual tool change. Lower cost N.C. drilling machines and boring mills with point-to-point control continue to be sold in reasonable numbers.

5. Multiple-Spindle Mills

Before the development of N.C., it was recognized that machine productivity on profiling and milling machines could be increased, where two or more identical parts were being produced, by using two or more cutting tools mounted on driven spindles moving in unison.

The set-up and unloading of multiple workpieces is more time-consuming than for a single workpiece, so the productivity gain on multi-spindle machines is somewhat less than a direct multiple of the number of spindles. One authority gives a figure of 1.6 as the net productivity increase of a two-spindle machine compared to a single-spindle machine.

Multi-spindle copy milling machines and profilers continue in use in the aerospace industry, providing a reasonably low net cost for machining, in spite of high template costs. The number of separately driven spindles moving in unison may be up to 6 or more.

The productivity gains of multi-spindle machines

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apply also to N.C. profilers and contour mills. A variation applicable to N.C. machines involves two spindles programmed to move independently. These are specialized and less commonplace type machines, such as a "skin mill", and may require up to 7-axis contouring control.

Due to physical size limitations, automatic tool changers are practical only on large size multi-spindle machines. Such machines perhaps provide the ultimate in productivity, but also involve enormous capital cost--in the range of several millions of dollars.

F) Cost of N.C. Machine Tools

Generalizations concerning the purchase price of various types of N.C. machine tools are virtually meaningless.

Within all categories of machine tools, the overriding factor affecting price is the size capacity of the machine. The larger the size of work the machine can handle, the greater the price.

Other factors which affect the price of N.C. machine tools include: the number of axes which are controlled, whether the type of control is contouring or point-to-point, the horsepower and type of drive motors, and the presence and capacity of automatic tool changers.

Individual N.C. machine tools may range in selling price from as little as $60,000.00 to several millions of dollars, depending on these and other factors.

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III. USE OF N.C. MACHINING BY THE AEROSPACE INDUSTRY

A) Economics of Powered Flight

In a modern subsonic aircraft, the payload weight is typically only about 15 percent of the gross weight of a fuelled, loaded aircraft.

In supersonic aircraft, the percentage of gross weight which is payload may be only half the above figure, and in space vehicles, much less again.

Alternately, to carry a given weight of payload a given distance, a reduction in the deadweight of aircraft means lower power requirements, hence lighter engines and less fuel, which again reduces airframe volume and structural requirements, and so on.

Therefore, aircraft manufacturers are willing to pay a high price to achieve weight reductions. This figure may vary from the order of one hundred dollars per pound of weight saved for unsophisticated subsonic aircraft, to many thousands of dollars per pound for space vehicles.

To achieve minimum weight, materials with a high strength to density ratio are used. For subsonic aircraft, aluminum alloys are the most widely used materials. However, aluminum alloys lose strength at elevated temperatures. Therefore, turbine engines, space vehicles, and high-performance supersonic aircraft use substantial amounts of titanium alloys, ultra high-strength steels, and super-alloys. These latter materials are frequently difficult to machine, requiring very rigid machine tools and spindle motors

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capable of high torque at low rotational speeds.

Also, to achieve minimum weight, it is necessary to exclude all material not absolutely necessary for carrying stresses. This leads to complex shapes.

Welding as a means of joining simple shapes to form complex shapes is not widely used in the aircraft industry, firstly because many of the best strength/ density ratio materials are not weldable, and secondly because welding frequently introduces defects which may reduce the stress-carrying ability of the fabrication.

Former practice has been to use rivetting to join simple shapes to form complex shapes. However, the rivets themselves and the necessary flanges and overlaps required for rivetting also add extra weight. Aside from the above, a large aircraft of all-rivetted construction could have several million rivet holes, which, at modern labour rates, would make it very expensive to build.

Modern practice is to machine the finished complex shape from a single homogeneous piece of material. It is not uncommon to have three-quarters of the starting weight of the original material stock machined away to produce the required part.

This extensive use of machining by the aerospace industry to produce complex shapes has been a major factor in the development of the capabilities of N.C. machine tools.

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USE OF N.C. MACHINING BY THE AEROSPACE INDUSTRY (cont.)

B) Economics of Scale - Production Runs

Aircraft are not made by the millions, nor even by the tens of thousands. A total production run of even a successful model of aircraft may be no more than a few hundred airplanes, spread over several years.

Therefore, mass production techniques such as used in the automobile industry are generally not applicable to the aircraft industry.

A production run for machined aircraft parts is typically several dozen pieces.

This is where N.C. machining techniques have been of great benefit to the industry. As previously mentioned, mechanical templates for older style template-guided machine tools, such as copy milling machines, are expensive to make. For a reasonably complex airframe component, the cost of such a template could be in the tens of thousands of dollars. This cost would not be significant if it were spread over a million parts. However, spread over only a few hundred parts, template cost is quite substantial.

By way of comparison, an N.C. machine tool program for the same part would be typically only a couple of hundred dollars. The savings are obvious. Hence, modern aircraft design makes extensive use of complex shapes machined by N.C. machine tools.

However, for reasons previously mentioned, multi-spindle template-guided machines still remain competi-

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tive with single-spindle N.C. machines on many applications at production run length encountered in the aircraft industry.

Most of the aircraft parts made by machining, except turbine engine parts, lack rotational symmetry. Hence, there is relatively little demand for turning in the aerospace industry. Most of the demand for machining is for drilling, boring, profiling, contouring, milling, and contour milling.

Specific types of machining and machine capabilities required by different sectors of the aerospace industry will be dealt with in greater detail in Section V of this report.

IV. QUALITY REQUIREMENTS FOR MACHINING OF PARTS FOR THE AEROSPACE INDUSTRY

A) Aircraft Safety Factors

Because the economics of flight will not permit much extra material to be included in aircraft structural components, there is a relatively small safety factor in such components. Such components can typically be expected to fail at 50 percent in excess of the maximum operating loads.

This rather small safety factor, plus the obvious serious consequences of a structural failure, necessitates that each and every part be free from geometric or structural defects.

This implies the need for high quality materials made to exacting specifications, careful control of all processing operations, and careful inspection by qualified quality control personnel after each stage of parts manufacture.

B) Standards and Specifications

All phases of aircraft materials and parts processing are governed by detailed written specifications and standards. This includes the materials used, all processing to which the materials may be subjected, quality control inspections including personnel qualifications, plus necessary requirements for plant facilities, tools, measuring devices, and administrative and inventory control procedures to be used in plants making parts for aircraft.

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QUALITY REQUIREMENTS FOR MACHINING OF PARTS FOR THE AERO-SPACE INDUSTRY (cont.)

Applicable specifications are various AMS (Aerospace Material Specification), MIL-Specs (U.S. Military), or F.A.R. (U.S. Federal Air Regulations) standards and specifications. In Canada, the preceding specifications are generally accepted, but may be supplemented or modified by DND (Department of National Defence) or other Federal Government specifications or regulations.

For shops performing machining operations on aerospace parts, the generally applicable specifications are MIL-Q-9858A governing quality program requirements, MIL-I-45208A governing inspection system requirements, and MIL-C-45662A governing calibration system requirements.

In addition to the aforementioned, various detailed specifications will govern the material and processes used on a particular type of part. For shops performing machining and other operations on a sub-contract basis, the necessary specifications required to be met will be advised by the purchaser.

C) Inspection of Plants

Major aerospace production plants are subject to inspection by representatives of various military and civilian authorities to insure that appropriate standards and specifications are being followed.

Plants which perform sub-contract work for major aerospace manufacturers are nearly always, themselves,

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inspected by quality control personnel from the major manufacturer.

For a sub-contractor performing N.C. machining, such an inspection would include the size and capabilities of the machine tools used, calibration and measuring systems, quality control personnel, facilities, and procedures. Such inspections also cover materials control systems. Machine shops which perform work for aerospace firms are generally required to have secure quarantine areas for incoming materials, and spearate, secure quarantine areas for non-conforming materials. Such shops are required to have and use detailed quality control procedures which are documented in a quality control manual.

After such an initial inspection by the manufacturer, and after the company has met the quality control inspection requirements, it is placed on the list of "approved vendors" for that particular aerospace manufacturer. Periodic re-inspections may be conducted from time to time.

Based on discussions with representatives of major aerospace manufacturers, it is the preference of each major manufacturer to conduct its own inspections, using its own quality control personnel.

Since all North American aerospace manufacturers work

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QUALITY REQUIREMENTS FOR MACHINING OF PARTS FOR THE AERO-SPACE INDUSTRY (cont.)

to the same general specifications*, it is likely that a machine shop approved by one manufacturer would be approved by others, although some manufacturers have their own practices and preferences on certain items. Manufacturers of sub-systems of aircraft, who, in turn, sub-contract out some machining work, will occasionally accept approval of machine shops as "approved vendors" who have been approved by the principal aerospace manufacturer for which the parts are ultimately destined, in lieu of conducting their own inspections.

The fact that a machine shop is on the "approved vendor" list of an aerospace manufacturer is no guarantee that the machine shop will obtain sub-contract machining work. As discussed in greater detail in Section V of this report, the machine shop generally must be low bidder on a particular "Request for Quotation" (RFQ) on specific parts sent out by the aerospace manufacturer.

However, not being listed as an "approved vendor" virtually guarantees that the machine shop in question will not receive an RFQ, nor would its quotation be considered by the manufacturer even if it were to quote.

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* The Ministry of Industry and Small Business Development of B.C. has sponsored seminars conducted by representatives of major aerospace manufacturers on this subject. More detailed information is obtainable from representatives of the Ministry's Vancouver office.

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QUALITY REQUIREMENTS FOR MACHINING OF PARTS FOR THE AERO-SPACE INDUSTRY (cont.)

There are some exceptions to the foregoing procedure. Both Boeing and General Electric advise that they will give "provisional approval" to prospective vendors on the basis of written information provided by that vendor, without physical plant inspection. Such "provisionally approved" vendors will receive RFQ's. If they appear to be the successful bidder on an RFQ, then an on-site plant inspection is conducted, prior to actually awarding the contract.

Examples of criteria that aerospace manufacturers require vendors to meet in order to become "approved" are shown in Appendix I.

D) Inspection of Parts during Manufacture

Assuming a machine shop has been successful in obtaining an order for machining of aircraft parts, a variety of inspections and control of these parts is necessary.

If the starting material is a casting or forging, such materials are usually provided by the purchaser. If the starting material is plate or bar stock, the machine shop may be required to procure the material directly. Materials for aerospace parts are either MIL Spec or AMS Specification materials. Materials conforming to these specifications nearly always come from the United States.

In either case, inspection of incoming materials is conducted to insure conformance to specification and

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QUALITY REQUIREMENTS FOR MACHINING OF PARTS FOR THE AEROSPACE INDUSTRY (cont.)

freedom from damage or deterioration. On occasion, NDT (Non-destructive testing) inspection of incoming material may be required. Any non-conforming materialmust be isolated to insure that it is not used in making aircraft parts.

Accepted incoming material is placed in secure storage until it is drawn out of storage for machining.

For machined parts, there may be a number of inspections required during the various machining operations. Each stage of processing and each inspection is generally recorded on a document, usually called a "travel card" or "traveller", which accompanies the part throughout the shop. Also recorded on the travel card are post-machining operations and inspections, such as deburring, plating, painting, etc. In general, each part is numbered with a general part or drawing number and an identification or serial number unique to each individual part.

The general intent of the above procedure is to be able, at any time in the future, to trace the exact history of manufacture of each individual part used in an aircraft.

A machine shop which has previously done machining work only for marine, automotive, or industrial customers may be surprised at the large amount of documentation and general paperwork required for the manufacture of aircraft parts. Nevertheless, this is a factor which is part of the requirements of the

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aerospace industry as a whole, and, therefore, must be accommodated by any machine shop seeking to do business with aerospace manufacturers.

E) Inspection of Parts by Purchaser

When the aerospace manufacturer receives the parts from the machine shop, the parts are subject to rigorous inspection. Such inspections will generally include conformance to required dimensions and tolerances, conformance to required surface finish, and freedom from any defects such as dents, gouges, or cracks.

Prior to acceptance of the received parts by the purchaser, the purchaser will also require that all necessary documentation providing "traceability" of the history of manufacture of each part is in order. If the documentation is not in order to the extent that "traceability" is lost, the purchaser may refuse to accept the parts, even if the parts are perfect in all physical respects.

F) Liability

In general, the only time a machine shop or other vendor is responsible for the actual service performance of an aircraft part is if the vendor has made a part or assembly to his own design. About the only B.C. firm to which this provision would apply would be Canadian Aircraft Products Ltd., who perform their own design and manufacture of some aircraft parts and assemblies.

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QUALITY REQUIREMENTS FOR MACHINING OF PARTS FOR THE AERO-SPACE INDUSTRY (cont.)

For virtually all sub-contract machining work, the vendor's responsibility (and warranty) is to insure that the parts are "built per drawing". The design responsibility and, hence, the responsibility for the service performance of the part, rests with the purchaser.

If the purchaser's receiving inspection indicates the parts do not conform to the drawings and specifications within allowable tolerances, he may return the parts to the vendor for corrective action, correct the non-conformance "in-house" (the costs of which are generally deducted from payment to the vendor), or, if the non-conformance is not repairable, simply refuse acceptance of the parts. In this latter case, the vendor receives no payment whatsoever, and may be liable for the cost of the starting material stock if this was supplied by the purchaser.

There is another level of liability exposure which a machine shop could conceivably face. This is the "latent defect", whereby the parts pass receiving inspection, but defects are found later in the process of aircraft assembly or even in flight.

The potential liability cost for "latent defects" is much higher. It should first be pointed out that "latent defects" in parts machined from supplied or approved materials, and shipped in "as machined" condition, or with simple finishing operations such as painting, are exceedingly unlikely. Any non-conformance would simply be geometrical, and would be

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QUALITY REQUIREMENTS FOR MACHINING OF PARTS FOR THE AEROSPACE INDUSTRY (cont.)

readily detected upon receiving inspection.

However, where post-machining operations include heat-treatment and/or certain plating operations, difficult-to-detect "latent defects" could conceivably be introduced into the parts (e.g. hydrogen introduced into the metal through improper control during a plating operation, or improper heat-treatment procedures developing incorrect hardness or strength levels in heat-treated parts). For these reasons, plating and heat-treating operations for aerospace parts are subject to exceedingly close process control and documentation.

Shops approved for performing such operations for aerospace parts are subject to extremely close inspection at frequent intervals to insure precise conformance to exacting specifications.

If a machine shop is required to have the parts heat-treated or plated after machining but prior to shipment to the purchaser, it must insure that this work is done according to specification at a facility approved by the purchaser.

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V. COMMON BUSINESS PRACTICES OF THE AEROSPACE INDUSTRY

A) General Outline

Among the thousands of firms engaged in making parts for the aerospace industry, there are, of course, wide variations in business practices and preferences. However, in the course of conducting interviews for this study, certain general patterns of business practices and preferences were found. In this section, generalized typical practices will be discussed (except where specific references are made). It should be remembered that a company dealing one-on-one with another company could conceivably find business practices which are substantially different from those outlined in this section.

The practice of sub-contracting the manufacture of parts and sub-assemblies is a way of life within the aerospace industry. There is no manufacturer of aircraft which makes "in-house" every part that goes into a completed aircraft.

Figures quoted by industry sources as to the percentage of aircraft parts which a manufacturer of complete aircraft purchases from sources outside his own organization range from 20 to 70 percent, with a rough average of 50 percent. Since the aerospace market is a multi-billion dollar per year business, the dollar volumes of sub-contract parts manufacture is also many billions.

There are many levels of sub-contracting carried out. If one principal manufacturer of aircraft has a large volume of work and another principal aircraft manufacturer does not, the busy firm may sub-contract to the not-so-busy firm substantial sub-assemblies of the aircraft and, hence, utilize otherwise idle production capacity of the latter. Examples of this are the current McDonnell-Douglas/Northrop cooperation on the F-18A military fighter program and the Boeing/Grumman cooperation on the Boeing 767 commercial airliner.

Also, within the aerospace industry, there are a number of manufacturers who have grown very large by specializing in manufacture of various sub-assemblies. Such specialized sub-assemblies include engines, landing gear, hydraulic actuators, fuel and air control systems and aviation electronics. This report will discuss these sub-sectors in greater detail in Section VIII

It is common practice for each principal aircraft manufacturer and each principal manufacturer of specialized sub-assemblies to, in turn, sub-contract work out to yet smaller firms, et cetera, through many levels of purchaser-vendor relationships.

This business relationship structure is not completely pyramidal in that very small firms may procure certain types of work directly from the very largest firms. The large firms have set up procurement administration systems capable of dealing efficiently with even very small firms.

In the course of gathering information for this report, all firms interviewed emphasized that they are

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most anxious to add to their list of "approved vendors" additional firms who are capable of providing quality parts, on schedule, at competitive prices.

Particularly the larger firms have departments and personnel whose jobs include seeking out additional "quality suppliers" and even encouraging inexperienced companies to become "quality suppliers" to the aerospace industry. In this latter regard, some of the larger firms provide a considerable amount of information and technical assistance to the inexperienced shops seeking to qualify to obtain work in machining aerospace parts.

The intermediate and smaller-sized aircraft manufacturers and manufacturers of specialized sub-assemblies are generally less capable of providing assistance to inexperienced potential suppliers. In this case, such manufacturers are relatively less interested in discussing business with machine shops who are unable to demonstrate that they already possess a considerable degree of proficiency in machining aerospace parts to acceptable quality standards.

B) Categories of Machining Work Sub-Contracted

1. "Outside Production"

Invariably, major aerospace manufacturers possess their own machining facilities--generally equipped with machine tools of large size and high technological capabilities (hence high capital cost). Also, such machine shops are staffed by highly

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skilled personnel who possess the latest state-of-the-art knowledge on machining techniques. Added to this are elaborately equipped and staffed quality control and inspection departments plus a large administrative staff. This means that such "in-house" machining facilities have very high overhead, such that shop costs in such facilities typically average $100-$150 (U.S. $) per hour.

The parts which go into aircraft range from parts with the most complex geometries made from difficult-to-machine materials with incredibly close tolerances and smooth finish, to parts of simple geometry made of easily-machined materials with readily achieved tolerances and finish. Of course, there is a continuous range of variations between the two extremes.

It is most common practice for major manufacturers to do "in-house" production on difficult parts and, hence, to fully utilize the extensive technological and management capabilities available.

On simpler parts, manufacturers seek to save money by farming out less demanding work to lower overhead machining facilities.

Generally, immediately after the design of a new model aircraft or sub-assembly has occurred, a management team performs a "make-or-buy" decision on each individual part which is to go into this new aircraft or sub-assembly.

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Machined parts which the major manufacturer believes are cheaper to buy than to make "in-house" are designate for "outside production". Parts so designated are then specified in "bid packages", which include drawings, tolerances, specifications, etc. These "bid packages" are then sent with a "Request for Quotation" (RFQ) by the Procurement or Purchasing Department to suitable "approved vendors".

The RFQ will specify whether material is to be supplied or purchased by the vendor. The RFQ will usually specify a fixed order quantity. In cases where the material is supplied by the purchaser, there is usually some scrap allowance, up to 10%. In this case, the order quantity may be modified somewhat, for example, a fixed number minus 0% plus 10%. In such a case, there is a slight bonus for a machine shop which avoids any scrap losses.

In some cases, the RFQ will be for "all requirements" over an extended period of time. In this case, the actual order quantity will depend on the success the major manufacturer has in selling its aircraft or sub-assemblies.

Usually, the RFQ will indicate the required delivery time or schedule. At this stage on "outside production" work, there is usually ample lead time, so work does not need to be performed on a "rush" basis.

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On "outside production" work, an N.C. machine shop generally will be expected to do its own programming for the part in question, and also to "prove" the program. This may involve several attempts in order to remove all program errors. In order to minimize possible scrap losses on expensive aerospace materials, most N.C. machine shops will "prove" their programs on non-aerospace materials. Where the starting material consists of forgings or castings of complex geometry supplied by the purchaser in quantities allowing only a small scrap allowance, it may be necessary to intentionally "scrap-the-first-part" for the purpose of proving the program. In such cases, this first part may need to be built up again several times by welding before the corrected program is finally proven correct.

It is obvious from the above that many "bugs" in the N.C. machine tool program could result in much extra work, and in tying up the N.C. machine tool for extended non-productive periods of time while the program is repeatedly corrected and re-tried. A skilled N.C. machine tool programmer who can produce an efficient and correct program in the minimum time will greatly assist an N.C. machine shop to obtain a reasonably good profit while bidding at a competitive price.

In preparing its bid, an N.C. machine shop should also consider the costs associated with the required quality control inspections and administrative control. Also, deburring is another operation which will add to costs. In machined aerospace parts, deburring and, frequently, hand-scraping, are nearly always required. It is not uncommon for the foregoing operations to add as much as 20% to the cost of a machined aerospace part.

In "outside production" work, major manufacturers nearly always wish to receive a completely finished part, ready for assembly into the aircraft or sub-assembly. Post-machining processing and finishing work may include heat-treatment, shot-peening, plating, anodizing, chemical coating, painting, etc. There are strict MIL and Aerospace specifications covering all of these operations, and such operations will need, nearly always, to be performed by shops which have been approved by the major manufacturer or other recognized authority.

Thus, the N.C. machine shop will need to add to its bid price the costs associated with performing such post-machining operations, generally on a further sub-contract basis.

When quotations on "outside production" parts are received from "approved vendors" by the major manufacturer, it is clearly understood that the vendor has quoted on the basis of providing parts of the specified quality made to the applicable specifications, and with all necessary documentation in order.

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COMMON BUSINESS PRACTICES OF THE AEROSPACE INDUSTRY (cont.)

The buyer for the major manufacturer will then generally select the successful bidder or bidders on the basis of lowest landed cost. Hence, transportation costs may tend to favour nearby vendors, but only slightly. The generally high value and relatively low weight of aircraft parts make the transportation cost of even continent-wide shipment a rather small percentage of "landed cost".

If a bidder advises on the quotation that his delivery time will be longer than that requested on the RFQ, this will work against his chances of being "successful bidder" if there are other shops which can deliver on schedule. On the other hand, there is no advantage to be gained from earlier-than-requested delivery. Major manufacturers have their production schedules which indicate when they need certain parts. In some cases, such manufacturers will actually refuse to accept "early delivery" of parts.

Once a vendor has obtained an order for a specific part in the "outside production" category, and provided that he meets quality requirements and delivery schedules, his chances of obtaining repeat orders for that part are very good.

If the contract award was based on "all-requirements-of" a part, for a period of time, a vendor who meets quality and delivery requirements and keeps his price increases within reasonable limits of inflation or justifiable material or labour

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cost increases, may find that the purchaser will simply extend the period of time of the contract and no re-bidding will be necessary.

In cases where the contract was for a fixed number of pieces, re-bidding for additional quantities may be required. However, a shop which already has a proven N.C. program on a specific part has a definite competitive advantage over an N.C. machine shop which does not.

Buyers for aerospace firms advise that loss of repeat orders by a vendor firm is relatively rare, and then is usually related to unsatisfactory quality or delivery performance, or to unreasonably high price increases.

They generally advise that the best opportunity for a machine shop to obtain "outside production" work on a "first time" basis is at the time of design of a new aircraft or sub-assemblies for new aircraft, when "bid packages" and "RFQ's" for entirely new parts are being sent out.

2. "Plant Offload"

A second category of sub-contract N.C. machining work is variously termed "plant offload", "diversion", "process farm-out", etc. This is machining work which is normally performed "in-house" by major manufacturers. However, if production problems develop or a sudden influx of orders suddenly overwhelms production capacity, most firms

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will "off-load" to sub-contract machine shops some of their machining work.

Such "offload" work comes up on short notice, and, being for normally "in-house" products, may involve more difficult machining techniques. This requires close liaison and exchange of information between the personnel of the major manufacturer and the sub-contracting machine shop.

Because of these factors, machine shops located geographically very close to the major manufacturer are greatly preferred over more distant shops. Beyond a distance of a few hundred miles from the major manufacturer, machine shops whose N.C. machine tools consist of relatively commonplace lathes and smaller-size 3- and 4-axis profilers and milling machines are given very little likelihood of obtaining much "offload" work in normal market circumstances.

For shops located in the greater Vancouver area of B.C., this more or less makes the Boeing works in the Seattle area, 150 miles (240 km) from Vancouver, about the only reasonable prospect for significant amounts of "plant offload" work, and then only when such work is unable to be accommodated by the considerable number of machine shops in the Seattle area.

On "plant offload" work, material is nearly always supplied by the major manufacturer, the job is bid as a "one-shot" contract with no expectation

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of repeat orders, and frequently "rush" delivery is required. On this type of work, there is generally a considerable amount of personal contact between production and quality control personnel from the major manufacturer and the machine shop performing the work. Where machine shop tools are compatible, the machine shop may be provided with N.C. control tapes, and sometimes jigs or other tooling, in order to assist the machine shop to produce the required parts as quickly as possible at minimum cost.

C) Terms of Payment

It is general practice within the aerospace industry that on smaller (i.e. below about $100,000.00) parts manufacture sub-contracts, advances or progress payments are not made to the vendor. Payment is made after receipt and acceptance by the purchaser. Hence, a machine shop seeking to obtain business from an aerospace manufacturer should insure that it has adequate working capital or available credit in order to carry such work until payment is eventually made on this basis.

D) Dealing with United States Aerospace Manufacturers

1. Shipment of Goods Across the Canada/U.S.A. Border

The latest G.A.T.T. (General Agreement on Trade and Tariffs) Agreement, which has been ratified by both Canada and the U.S.A., provides for duty-free shipment of commercial aircraft parts in

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both directions across the border.

Although duty-free, such shipments are subject to customs inspection. Customs clearance papers must be correctly made out, otherwise delays in shipments may be encountered.

The status of military aerospace parts is not as clearly defined. There may be political and security considerations as well as customs regulations to consider, which may require specific clearance documents or licences which could inhibit the free flow of such goods across the border, and, hence, would work against Canadian companies seeking sub-contract work to produce such goods.

2. Military and Political Considerations

On certain types of military aerospace parts, particularly for use in hardware of a sensitive nature, for the exclusive use of the U.S. armed forces, Canadian citizens may be unable to receive information on such items, let alone manufacture parts for these items.

This should be less of a consideration with hardware associated with the NATO and NORAD alliances. There are Canadian-owned aerospace firms which regularly do business directly with U.S. military forces. However, some political assistance in such instances might be required.

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3. Industrial Offsets

The term "industrial offsets" is a term used to describe agreements made between the Canadian government and certain major U.S. aerospace manufacturers linked to Canada's purchase of military aircraft from these firms.

Under these agreements, the specified U.S. aerospace manufacturers are obligated to spend (directly or indirectly) substantial sums in Canada, most of this being related in various ways to aerospace production in Canada.

The two principal U.S. manufacturers concerned at present are:

a) Lockheed California Company--This agreement is related to Canada's purchase of the CP-140 "Aurora" patrol aircraft. The term of this offset agreement is 1975 through 1995, and the dollar value to Canada is quoted as $938 million (U.S. $).

b) McDonnell Douglas Corporation--This agreement is related to Canada's purchase of the CF-18A fighter aircraft. The term of this offset agreement is 1980 through 1995, and the dollar value to Canada is quoted as $2.91 billion (Cdn. $).

A substantial portion of the dollar values quoted for these offset agreements will involve sub-contract work to Canadian aerospace manufacturers (or at least to plants located in Canada).

As previously mentioned, sub-contracting to other firms in the industry is a way of life in the U.S. aerospace industry. It is not surprising, then, that offset commitments are spread around among a number of cooperating U.S. firms in an arrangement (often, a contractual obligation) involving "transfer of offset credits" among the participating firms. For example, General Electric, who will be supplying the engines for the CF-18A, has reportedly contracted with McDonnell Douglas to place about $800 million in offset work in Canada (not all in aerospace subcontracting, however).

The foregoing could serve to favour a Canadian firm seeking to do business with a particular U.S. firm.

Lockhead, whose offset contract has been running for five years, reports that it is ahead of schedule on its offset commitments. Therefore, Canadian firms seeking to do business with Lockheed or its principal sub-contractors, cannot, at this time, expect any special considerations when quoting on business.

However, part of lockheed's contractual obligation requires Lockheed ". . . to render technical and marketing assistance to the Canadian aerospace industry . . . ." In this regard, Lockheed

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personnel were found to be of considerable assistance in the gathering of information for this study, and may also be expected to provide assistance to B.C. machine shops seeking U.S. aerospace work.

At the time information for this report was being obtained (July-September 1980), McDonnell Douglas and its principal sub-contractors (Northrop, General Electric, Cleveland Pneumatic, etc.) had reportedly not finalized the program by which offset commitments would be met. Nevertheless, some or all of the following programs seem likely as the McDonnell Douglas consortium seeks to meet its offset commitments:

a) Expansion of the McDonnell Douglas plant in Malton, Ont., and increased sub-contract work let through this plant.

b) Major airframe packages sub-contracted to one or more of the following companies:

   i) Bristol Aerospace Ltd., Winnipeg, Man.
   ii) Canadair Ltd., St. Laurent, Que.
   iii) De Havilland Aircraft of Canada, Ltd., Toronto, Ont.
   iv) Enheat Ltd., Aircraft Div., Amherst, N.S.
   v) Fleet Industries, Div. of Ronyx Corp. Ltd., Fort Erie, Ont.
   vi) McDonnell Douglas Canada Ltd., Malton, Ont.

c) Building a major new aerospace machining

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facility, to be located in the Province of Quebec, with McDonnell Douglas equity participation.

d) Outside production of General Electric (G.E.) engine parts at Bristol Aerospace Ltd., Winnipeg, Man. and/or other locations.

e) A new G.E. engine plant (location not specified).

f) A new G.E. Blade and Vane Plant (location not specified).

g) Increased purchases of G.E. industrial components from Canadian sources.

Likely related to the McDonnell Douglas offset commitment is the recent announcement (Sept. 23, 1980) of a new aluminum forging plant, Aero-Forge Ltd., to be built in Vancouver, B.C., with the assistance of Continental Forge Co. of Compton, California. This plant reportedly will make aluminum forgings for the airframe of the McDonnell Douglas DC-10.

As preveiously mentioned, perhaps the best time for firms seeking to break into the market to solicit work is at the beginning of an aircraft building program. In this regard, major manufacturers and principal sub-contractors for the CF-18A program may be considered to offer good potential.

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4. Currency Fluctuations

U.S. aerospace firms tend to award contracts for "outside production" on the basis of lowest landed cost, which, of course, is computed in U.S. dollars. The present lower value of the Canadian dollar relative to its U.S. counterpart should serve to put Canadian suppliers in a more competitive position.

However, possible fluctuations in relative currency values should be considered if Canadian companies intend to enter into long-term commitments.

5. Recommended Business Practices for Machine Shops Soliciting Aerospace Machining

This section is a distillation of practices and techniques, recommended by procurement and quality control personnel from the many aerospace firms interviewed, for shops seeking to enter the market or to obtain new business in aerospace machining.

First and foremost, the machine shop must appreciate the commitment to quality of the aerospace industry. Shop personnel should have studied and become familiar with the quality control procedures and specifications of the industry. The machine shop should have a quality control manual.

Before making calls on buyers in the industry, it is also recommended that the shop prepare a

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written description of itself, or even a sales brochure, outlining in some detail its machine tools, experience of personnel, general capabilities, capabilities with respect to specialized machining operations or finishing operations, inspection equipment and quality control systems, and experience in machining of aerospace parts. The machine shop representative who calls on buyers should also have available credit references and/or details on the company's capitalization, shop costs, and present machine utilization.

In general, advance appointments to see buyers are necessary. Unannounced visits are usually not possible due to tight plant security at aerospace plants.

It is usually advisable to see a number of different buyers in a large aerospace corporation. For example, the Boeing Company operates many different divisions, each with its own procurement and outside production departments. The Boeing "Directory of Buyers" numbers 125 pages. A person soliciting machining work from Boeing could easily spend several days visiting buyers at the various Boeing plants just in the Seattle area.

As curious as it may seem, a machine shop with no experience whatsoever in aerospace work stands the greatest chance of obtaining its first aerospace work from the largest aerospace manufacturers. Recognizing that a first step must be taken somewhere in order to keep the industry supplied

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with "quality vendors", buyers for large firms will frequently "take a flyer" on a shop which has no previous aerospace experience, provided that the buyer is satisfied the shop has met quality control system requirements (which may entail inspections by quality control personnel), bids at competitive prices, and generally convinces the buyer of its dedication to do good work. Personal visits by machine shop representatives to buyers in order to obtain the "first" aerospace work is strongly recommended.

Buyers and procurement personnel for smaller aerospace manufacturers are less inclined to "take a flyer" on machine shops unable to demonstrate previous aerospace experience.

After the machine shop without aerospace experience has become an "approved vendor" or "provisionally approved vendor" from the point of view of the quality assurance department, and the shop has made a favourable impression on a particular buyer, that buyer is likely to send the shop a "bid package", which includes an "RFQ", when work is required which the buyer believes is within the capabilities of the machine shop. Typically, the "first" aerospace work an inexperienced shop is asked to bid upon may be relatively simple work of relatively low dollar value.

Once the machine shop has receive an RFQ, there are several things the shop can do to ruin its chances of obtaining any future work or additional

RFQ's from that particular buyer, or even from the company as a whole. The first and most blatant error is to fail to respond to the RFQ. This commonly results in the machine shop's removal from the "approved vendors" list. Nearly as bad is to return the RFQ marked "unable to quote", with no explanation. If there is a valid reason why the shop is, indeed, unable to quote, for example being too busy at the time or considering the work beyond its capabilities, there should be a note of explanation provided if the firm wishes to receive future RFQ's.

Once the inexperienced machine shop has received the RFQ and the generally large volume of drawings and specifications accompanying it in the "bid package", the machine shop may then proceed to prepare a quotation. Buyers recount with some amusement the syndrome which frequently occurs at this point. The person preparing the quotation gazes with horror at the mountainous mass of papers confronting him and quickly develops cold feet. He, therefore, builds into his price provisions for all kinds of unrealistic contingencies. The net result is that his quoted price is far in excess of that of the successful bidder, and, of course, that shop does not receive the work.

Procurement personnel for aerospace manufacturers strongly advise unsuccessful bidders to contact them to determine, in general terms, how close the shop came on its quoted price, compared to

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the price quoted by the successful bidder.

Many buyers advise that they will assist the shop personnel in reviewing their pricing formula to discover where they went wrong. Buyers point out that their own companies are experienced in machining aerospace parts, and, therefore, have a very good idea of the cost of such machining work. Some buyers have advised that they may also turn down quotations where the price is unreasonably low, the the extent that the shop is certain to lose money.

After perhaps several quotations have been submitted, the shop may become successful bidder for aerospace machining work. Here, too, a shop may ruin its chances for future work by either producing parts of unacceptable quality or by failing to deliver the parts by the quoted delivery date, without some sort of explanation, well in advance, of valid reasons for late delivery.

A shop which produces acceptable parts and delivers on schedule is very likely to obtain repeat business from the aerospace manufacturer, frequently of greater value and complexity than the initial order. Such a shop can also claim aerospace experience when soliciting business from other aerospace manufacturers.

Procurement personnel stress the importance of patience on the part of the machine shop. Months might elapse between visits to a buyer and

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receipt of an RFQ.

Personal visits or telephone calls to buyers on a periodic basis are also recommended in order to maintain a certain level of personal contact.

Purchasing personnel for a number of aerospace firms advise that certain machine shops, located in B.C., which had been soliciting machining work, have already committed some of the marketing blunders mentioned above. This has reduced the chances these particular machine shops have of obtaining work from these aerospace manufacturers.

It is a regretable situation when machine shops, which may have put a considerable amount of time and effort into the establishment of suitable quality control systems, waste this effort through poor marketing practices.

VI. THE AEROSPACE MARKET

A) General

The North American aerospace market in all sectors in 1979 amounted to nearly U.S. $31 billion. Of this, the Canadian aerospace market amounted to U.S. $1.1 billion. These two markets will be discussed in greater detail later.

From the above figures, Canada's disproportionately small share of the market underlines the well-known fact that Canada is a net importer of aircraft and aircraft parts.

On the other hand, the U.S. is a large net exporter of aircraft and aircraft parts. The aerospace industry is of great benefit to the U.S. balance of payments on a world-wide basis.

B) The United States Aerospace Market

1. Distribution and Value

Based on a reasonably comprehensive data base, the United States aerospace market had total sales in 1979 of $29,809 million (all dollar figures used in this sub-section are U.S. $). These figures include production of rockets, missiles and space vehicles as well as aircraft. Included in the above figures are the value of both complete aircraft and aerospace vehicles, aerospace parts and equipment, and engines and engine parts (including rocket engines). Aerospace electronic systems sales figures are not included.

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THE AEROSPACE MARKET (cont.)

On the basis of a qualitative assessment of the data, more than half the total U.S. aerospace production is concerned with military aerospace hardware.

In Appendix II-B, we have shown a breakdown of the U.S. aerospace market by product sales (based on the three categories listed above) and geographic distribution of production facilities in four geographic regions--California, the western U.S. exclusive of California, central U.S., and eastern U.S.

Some interesting information is gleaned from this table. Engine and engine parts production is heavily concentrated (71% of production) in the eastern U.S.

On the other hand, production of complete aircraft is more heavily concentrated in the western and central U.S. than in the east.

Production of aircraft parts seems to be concentrated in regions of greatest population density, with the eastern U.S. having 42% of the total, followed by California with 31%.

On balance, total aerospace production appears relatively uniformly distributed across the continental U.S.A.

In Appendix II-A we have listed the 33 major corporations in the U.S. aerospace industry, using

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the criterion of aggregate corporate annual sales exceeding $100 million. Also shown are the principal products of these firms.

Sales by these corporations and their subsidiaries account for 83% of the U.S. aerospace market. If qualified B.C. machine shops seek to solicit aerospace machining work in the U.S., corporations on this list are likely to be the best potential customers.

In order to evaluate the market potential for much smaller corporations seeking to enter the aerospace parts market, we have used the same data to determine the share of the market presently enjoyed by smaller firms. We have used as a criterion for "smaller firm" annual sales of aerospace related goods of below $5 million.

In the field of engines and engine parts, such smaller firms possess 2.17% of the market, amounting to $151 million.

In the field of aircraft parts and equipment, smaller firms posses 14.58% of the market, amounting to $785 million.

The above figures do not include figures for aerospace electronic or communication systems, or for complete aircraft. Therefore, it is likely that a substantial portion of the total value given is for machined aircraft parts. However, the exact value of machining work cannot be determined from the data available.

2. Present Market Status--Qualitative

The following information is qualitative in nature

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THE AEROSPACE MARKET (cont.)

and is based on discussions held with various representatives of U.S. aerospace firms.

During 1979 and during the first quarter of 1980, both the commercial and military sectors of the U.S. aerospace industry were operating at, or above, capacity.

Because modern aircraft involve more machined parts and fewer sheet metal parts than older aircraft, and because the newest designs include some components which can only be made effectively on 5-axis N.C. machine tools, this created a severe shortage of machining capacity in the aerospace industry. Because 5-axis N.C. machine tools are relatively recent innovations, there was a particularly desparate shortage of 5-axis machining capacity.

This resulted in aircraft manufacturers attempting to sub-contract a substantial volume of their machining requirements on the basis of "plant offload".

At the end of the first quarter of 1980, the effects of the U.S. recession began to be felt in the aerospace industry. This manifested itself in a "stretching-out" of required delivery dates for commercial aircraft and a slowing down of the rate of new orders for such aircraft.

This opened up a substantial amount of machine tool capacity within the aircraft manufacturing

THE AEROSPACE MARKET (cont.)

plants. At the time data for this study was gathered (July-September 1980), there was virtually no "plant offload" type work being let for turning, very little for 3 and 4-axis profiling and milling, but still a substantial amount for 5-axis profiling and milling, due to the general shortage of such machine tools and long delivery times for new equipment of this type.

Smaller firms doing sub-contract "outside production" of parts for commercial airliners had to share in the slowdown of the required rate of delivery of such parts, hence the "plant offload" work they in turn sub-contracted also dropped off sharply.

The military sector has been relatively unaffected by the recession at present and remains reasonably busy. Some of the military part machining work is presently being "offloaded" to the presently slow commercial plants.

Nearly all aircraft manufacturers advised that they have large 5-axis N.C. profilers on order, but delivery times for such machines range up to 3 years. Therefore, the shortage of 5-axis profilers may continue for some time yet.

The Boeing Company is building a large new machining facility, but most other firms interviewed advise that they will simply be replacing obsolete machine tools with modern machine tools within existing plant facilities.

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C) The Canadian Aerospace Market

1. Distribution and Value

Detailed information on the Canadian aerospace market is not readily available. Based on figures quoted by Statistics Canada, total sales by the Canadian aerospace market (all sectors, including aircraft overhaul) in 1979 was $1,286 million (Canadian $) or abour U.S. $1,093 million.

In Appendix II-C, we have listed the principal Canadian aerospace firms and their principal products.

Although dollar figures for production by plant were not obtainable, it can be seen from the appendix that the Canadian aerospace industry is concentrated in the Montreal and Toronto areas, with no major production facility west of Winnipeg.

2. Present Market Status--Qualitative

Except for McDonnell Douglas's commercial airliner wing plant in Toronto, the Canadian aerospace industry remained relatively unaffected by the current recession, which appears to be biting more deeply into the U.S. than Canada.

Both Canadian manufacturers of complete aircraft, De Havilland and Canadair (both owned by the Canadian government), appear to be in the early stages of successful programs for mid-sized aircraft.

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THE AEROSPACE MARKET (cont.)

The Canadair "Challenger" business jet appears to be selling well. Also, Canadair is making substantial sections of the Lockheed P-140 patrol aircraft as part of the industrial offsets agreement with Lockheed.

De Havilland continues to produce about seven DHC-6 "Twin Otter" aircraft per month and has started delivery on over 100 orders for the DASH-7 fifty passenger STOL turboprop aircraft.

The Canadian-made aircraft mentioned generally use sheet metal construction techniques and require relatively less 5-axis machining than required by U.S. designed military fighter aircraft or new large commercial jet airliners.

De Havilland advises that, at present, it has requirements for very little "plant offload" work, but has "outside production" of various parts performed on an on-going basis--mostly to the 45 qualified shops in the Toronto area. Most of De Havilland's machining work involves no more than 4-axis N.C. machines, and the very largest parts machined measure 8 feet by 4 feet.

Similarly, Canadair is having some "outside production" work done for the "Challenger", including some tail-section parts being made by Canadian Aircraft Products Ltd. in Richmond, B.C.

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VII. FUTURE OUTLOOK FOR THE AEROSPACE INDUSTRY

A) United States

1. Military

Representatives of the U.S. aerospace industry consider the outlook for military aircraft and other aerospace military hardware to be very good.

They cite the recognition by political authorities of the growing deficiency in conventional and strategic military hardware of the western alliance relative to the eastern block nations. This is likely to lead to building programs on many of the military aerospace vehicles presently in the design and test stages. New programs include the development of "airplane-like" cruise missiles and the proposed "MX" ballistic missile system.

With respect to military aircraft on which production is now beginning, the McDonnell Douglas/ Northrop consortium expects to sell nearly 1600 F-18A fighters by 1994 (including the 137 purchased by Canada). Production will peak around 1986.

The F-18A airframe involves a large amount of 5-axis machining. At least 20% of the airframe parts cannot be made economically on N.C. machine tools of less than 5-axis capability. Most of the F-18A airframe is of aluminum alloys, but there are also substantial amounts of titanium alloys, plus significant amounts of ultra-high-

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strength steels and composites. These latter materials are generally more difficult to machine than aluminum.

The F-18A will use the F404 engine made by General Electric, and landing gear made by Cleveland Pneumatic. Therefore, these firms may be expected to become increasingly busy as the F-18A program gathers momentum.

It should be remembered that military building programs can be altered drastically on short notice, depending on the political climate prevailing and on the state of world affairs. It was abrupt cut-backs in military and space building programs which led to the industry-wide slump of the late 1960's and early 1970's.

2. Commercial Aircraft

The present relatively mild slump in construction of commercial airliners is attributed to the current U.S. recession and the rising cost of fuel, hence, rising air travel costs, causing a reduction in total air traffic. This, in turn, led airlines to delay taking delivery of new aircraft and to cut back on new orders.

Opinions vary as to the likely duration of the current downturn--from a few months to up to 3 years.

However, industry sources invariably view the

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medium and long-term prospects as very good. They cite the following reasons:

a) While rising fuel costs will invariably raise the cost of all forms of transportation, and, hence, may reduce the total amount of travelling done by the public to a certain extent, the fuel consumed per passenger-mile for commercial air travel is considerably less than for the private passenger automobile. Therefore, air travel may be expected to grow at the expense of the automobile industry.

b) Many of the world's major airlines need to replace their ageing fleets. New, quieter and more fuel-efficient airliners now on the drawing boards or in test flight stages will make purchase of new aircraft attractive to airlines, as fuel costs continue to rise. Such new aircraft include the DC-9-80 and the new Boeing 757 and 767 models.

Since fuel efficiency is now a major selling point on new commercial aircraft, and recalling the earlier discussion in the report on the economics of flight, it is not surprising that the new airliner designs are employing lighter-weight all-machined construction over rivetted sheet-metal construction to a large extent. As with high performance fighter construction, this will increase the need for N.C. machine tools generally, but will, in particular, require more 5-axis machining capability.

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Boeing is presently bulding a major new machining facility in Kent, Washington, to supplement its central manufacturing facility in Auburn which possesses 80 N.C. machine tools including fifteen 5-axis machines.

B) Canada

1. Military

Related to the offset package associated with Canada's purchase of the CF-18A fighter, a number of Canadian manufacturers are presently preparing bids on major airframe sub-assemblies for this aircraft. Firms presently bidding are Bristol, Canadair, De Havilland, Enheat, Fleet, and McDonnell Douglas of Canada Ltd.

As previously mentioned in the discussion on offsets, General Electric is also expected to build facilities and place additional work in Canada.

2. Commercial Aircraft

De Havilland's recent announcement of the DASH-8 has been met with enthusiastic response. This thirty passenger turbo-prop aircraft is sized midway between the 17-passenger "Twin Otter" and the 50-passenger DASH-7. Although the DASH-8 is at least 3 years from production, De Havilland reports that they already have received 73 orders for this aircraft.

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FUTURE OUTLOOK FOR THE AEROSPACE INDUSTRY (cont.)

Because the De Havilland plant is already nearly at capacity, it is likely that large sub-sections of the DASH-8 will be built by outside production.

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VIII. SPECIFIC MACHINING REQUIREMENTS BY PRODUCT SECTOR

A) General

In the terms of reference for this study, it was requested that four specific product groups used in aircraft manufacture be explored in depth. These product groups are:

a) Airframe
b) Engines
c) Hydraulics
d) Landing Gear

Aerospace firms falling into these categories were to be asked to provide information concerning their backlog of machining hours, the degree to which they intended to increase their own N.C. machining capabilities, when they might become self-sufficient, and other questions.

In the course of visiting various plants and conducting interviews, it became apparent that some of these questions were based on assumptions concerning the aerospace industry which were found to be incorrect upon closer examination. In other words, it is difficult to provide a straightforward answer to some of the foregoing questions.

The first difficulty is that manufacturers did not fall neatly into the categories provided. An example was Héroux Inc. in Montreal. Generally described as a landing gear manufacturer, this company was also observed to be making hydraulic actuator parts and airframe components--simultaneously in the same plant.

SPECIFIC MACHINING REQUIREMENTS BY PRODUCT SECTOR (cont.)

The distinction between hydraulic and landing gear manufacturers is especially nebulous.

The second difficulty arises concerning the phrase "backlog of machining hours". The aircraft industry is such that aircraft and aircraft parts are built to order, and rarely for stock. Hence, as long as there are orders on the books, there is a backlog of machining hours.

It is necessary in this case to think in dynamic terms of machine tools production rates versus aircraft delivery schedules. A good example is the one recently discussed, whereby a stretching out of delivery dates for commercial airliners left the accumulated backlog of machining hours relatively unchanged, but changed the industry from a condition of having insufficient machining capacity to a condition of having adequate machining capacity (5-axis excepted).

The last area of difficulty is the one dealing with the term "self-sufficient". Companies within the aero-space industry have become so accustomed to dealing with one another in various buyer/seller relationships that no company whatsoever indicated that its objective was to reach a condition whereby every machined part it used was machined in its own facilities.

Recalling a previous discussion, virtually all manufacturers of aircraft and aircraft sub-systems go through a "make-or-buy" decision making process on each part at the time of design.

If a particular part ends up in the "buy" category, it is sub-contracted to another company for "outside production".

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SPECIFIC MACHINING REQUIREMENTS BY PRODUCT SECTOR (cont.)

If a particular part is in the "make" category, it is destined to be made by "in-house" production facilities. If something goes wrong with "in-house" production facilities or scheduling, or if the manufacturer is suddenly overwhelmed by an unexpected influx of orders, production of this particular "make" part may be "offloaded" to another company, frequently as a rush job.

Incidentally, when talking to people in the aerospace industry, it is not unusual to hear the word "offload" used as a noun, verb and adjective in a variety of contexts. In this report, for the purposes of clarity, we have attempted to reserve use of the words "offloading", "offloaded", and "plant offload" to describe the category of sub-contract work just mentioned.

Larger firms tend to stick by the original "make-buy" decision quite rigidly. In slow times, such firms may actually lay off some of their own production personnel while continuing to buy all of their requirements of a particular "outside production" part from an outside source.

Smaller manufacturers tend to be less rigid, and hence the difference between "outside production" and "plant offload" work becomes less distinct. In slow times, as the "outside production" purchase agreement for a particular part expires, such manufacturers may commence production of that part "in-house" in order to keep a load on their own production facilities.

Most manufacturers consider that to have a substantial amount of "plant offload" category work sub-contracted is an undesirable situation. In such cases, the manufacturer will likely increase his "in-house" production capabilities to reduce or eliminate the "plant offload" work. However, to have a substantial amount of "outside production" category work sub-contracted is considered to be a normal situation.

If the aerospace industry as a whole is taken to include firms which perform "outside production" work for major manufacturers, then the normal state of affairs is that the industry, as a whole, is self-sufficient. Where temporary aberrations occur, such as in the current shortage of 5-axis profiling capacity, the industry, as a whole, moves to correct such aberrations. Present examples of this include the expansion of Boeing's machining facilities, and construction of new independent facilities, such as the proposed ICAM Aerospace Corp. plant. A basic supply-and-demand situation prevails, with equilibrium eventually being achieved.

Having thus prequalified some of the answers, we will now consider the four product groups in greater detail.

B) Airframe

1. General Considerations

The current thrust in airframe construction techniques is toward integrally stiffened panels.

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Older construction techniques involved machining stiffeners and frames on 3-axis milling machines. Then a sheet metal aluminum skin was fastened to the frames by rivetting.

When integrally stiffened panels are used, skin and stiffeners are machined together from a single plate. Weight savings of up to 10% can be achieved by this technique. Also, a great reduction in the number of parts required is achieved, yielding lower assembly costs.

Machining integrally stiffened panels requires 5-axis contouring N.C. profilers. Large aircraft, of course, have large panels. Since the integrally stiffened panel technique yields lighter weight, hence better performance or better fuel efficiency, all aircraft manufacturers wish to use this type of construction--hence, the current shortage of 5-axis profilers, particularly of large size.

As previously mentioned, manufacturers generally tend to keep more complex and difficult machining work for "in-house" production, and send simpler, less demanding work for "outside production".

2. Machining Requirements, Size and Configurations

It is worth mentioning, at this point, that figures quoted in this report for proportions of manufactured goods made by "outside production" are based on the numbers of parts used. Since parts made by "outside production" tend to be smaller and less complex, and since "outside production" is frequently performed by low overhead facilities, the statement that "50 percent of the required parts are made by outside production" may mean no more than 10 or 15 percent of the dollar value of the total parts requirement, based on landed price, is actually spent on "outside production"

It is likely that major aircraft and airframe manufacturers will retain much of the 5-axis work for "in-house" production--particularly on larger size, integrally stiffened panels.

However, even on advanced designs of aircraft, such as the F-18A, the percentage of parts which must be machined on 5-axis profilers is relatively small. On the F-18A, this has been estimated at 20% of the total number of airframe parts. This leaves a large number of parts which can be machined on 3 and 4-axis machines.

On large airplanes, such as the Boeing commercial airliners, individual machined parts, such as integrally stiffened wing panels, can measure perhaps 10 feet by 30 feet in size. However, even the largest aircraft contain a substantial number of reasonably small machined parts. The geometry may cover a wide range of complex shapes.

Machining operations required for production of airframe parts consist mostly of profiling,

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milling and contour milling, with a lesser amount of drilling and boring. There is a negligible amount of turning required for aircraft airframes, but some large diameter turning, up to 10 feet in diameter, may be needed for rocket and missile structural components.

3. Materials Used

Aluminum alloys continue to be the most widely used materials for airframe parts, although the use of more difficult-to-machine titanium alloys and ultra-high-strength steels, is generally increasing.

The above materials are generally supplied in the form of forgings, plate or bar stock. If forgings are used, these are nearly always supplied to the sub-contractor by the major airframe manufacturer. If plate or bar stock is used, the vendor may sometimes be required to obtain the specified material stock on his own.

Composite materials are beginning to find application in aircraft skin and frame construction. The Canadair "Challenger" is reported to use some small sections made of graphite fiber composite. This material is normally formed into shape during manufacture. If it is necessary to machine graphite fiber composite, diamond-cutting tools must be used.

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SPECIFIC MACHINING REQUIREMENTS BY PRODUCT SECTOR (cont.)

4. Tolerances and Surface Finish

Machining tolerances for airframe parts are not exceptionally rigorous, at least when compared to other sectors of the aerospace industry. It is rare that tolerances of better than ± .002 inches are required, and in many areas of a typical part, tolerances much greater than this will be allowed.

Likewise, exceptionally smooth surface finishes are not generally required.

5. Finishing Operations and Inspection

For airframe parts made of aluminum alloys, generally the only finishing operations required after deburring consist of chemical coating, anodizing and/or painting. For alloys of other metals, shot-peening, heat-treating and/or plating may also be required.

On aluminum parts, inspections generally consist of dimensional checks and fluorescent-dye-penetrant NDT inspection. Other alloys may require different NDT techniques.

6. Market Size and Distance

The total value of U.S. aircraft production in 1979 was over $17 billion. It is therefore likely that the total value of outside production sub-contracts of airframe machined parts to firms,

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both large and small, totalled several billion dollars.

In the U.S., unlike Canada, production of aircraft and airframe parts tends to be more concentrated in the western part of the country. This works to the advantage of B.C. firms aspiring to manufacture parts for this sector of the industry.

In the following sub-sections, the market potential for various geographic regions will be examined.

a) Washington State

The southwestern corner of British Columbia is especially favoured geographically due to its close proximity to the very large Boeing Company works in the Seattle area. Vancouver, B.C. is less than 150 miles (240 km) by road from Seattle, and Victoria, B.C. is still closer, although separated by water.

The importance of the Seattle works of the Boeing Company to any aerospace aspirations by B.C. industry is best appreciated when it is realized that the value of shipments made from the Seattle area plants of Boeing in 1979 was nearly three times the value of shipments from the entire Canadian aerospace industry.

Because of the great potential for airframe

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sub-contract machining business, a few comments specifically concerning the Boeing Company are in order.

First, the Boeing Company, based on 1979 sales figures, is the largest aircraft manufacturer in the United States. It is unquestionably the world's largest manufacturer of commercial aircraft. Somewhat over half of Boeing's total business is related to commercial aircraft. However, it is also heavily involved in military aerospace production--notably rocket missiles and cruise missiles. Boeing has also diversified somewhat to produce ships (notably hydrofoils), military surface vehicles, and other "non-flight" products. Hence, its requirements for "outside production" will undoubtedly extend beyond airframe parts.

Boeing has its own major machining facility at Auburn, Washington, which operates 196 machine tools, 80 of which are N.C., and 15 of these are 5-axis. Boeing is also presently building a major new machining facility at Kent, Washington. This will probably be heavily oriented towards 5-axis N.C. contouring.

Boeing is presently in the post-design, pre-production stages of two major new airliner designs, the 757 and 767, scheduled for test flights in 1981.

SPECIFIC MACHINING REQUIREMENTS BY PRODUCT SECTOR (cont.)

Boeing advises that it typically has about 20-30% of its airframe components made by "outside production" (based on parts count). Preference is given to Seattle area firms on such work, but Boeing regularly has "outside production" work performed in California and even further afield in the U.S. Therefore, the relatively short distance between southwestern B.C. and Seattle should not present much of a problem to B.C. shops. Likewise, with the current G.A.T.T. agreement in effect, the international boundary should not inhibit the flow of parts, at least for the commercial sector.

At this time, Boeing has an uspecified trade offset agreement with Canada, so Canadian suppliers can possibly expect some preferrential treatment in this regard. Like most aerospace manufacturers, Boeing tends to award "outside production" sub-contracts on the basis of lowest landed cost. The present devalued condition of the Canadian dollar is likely to favour Canadian shops bidding on this work.

The Boeing Company is organized into many corporate groups and divisions. It operates various of its divisions, for example the 747 division of the Boeing Commercial Airplane Company, essentially as separate administrative units. Within each such administrative unit, there may be a manager for outside production, various contract administrators, etc., plus many buyers responsible for purchasing specific categories of machined parts. The representative of a firm actively soliciting business from the Boeing Co. in the Seattle area should be prepared to spend several days in the effort, visiting perhaps dozens of buyers in many different corporate groups and divisions. It is also recommended that a representative of a relatively small business, which is soliciting work from Boeing, should contact the Administrator--Small Business Programs in each division for assistance and information. Appointments should be made in advance before visiting buyers or administrative personnel. Boeing publishes a 125 page "Directory of Buyers", available at their main offices, which is virtually essentail for any organized sales effort aimed at this large complex.

Boeing advises that it also provides expertise and assistance to its suppliers for quality control improvement.

b) California

With respect to market potential with U.S. airframe firms other than Boeing, there exists a significant potential market in the Los Angeles area, about 1000 air miles distant from Vancouver.

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SPECIFIC MACHINING REQUIREMENTS BY PRODUCT SECTOR (cont.)

i) Lockheed

Lockheed has no major new building programs at present and outside production work for its existing programs are fully placed. Likewise, its Canadian offset obligations are more than met with existing programs. However, Lockheed personnel are helpful in providing technical and marketing assistance.

ii) McDonnell Douglas

McDonnell Douglas plants in California are mainly concerned with commercial aircraft such as the DC-9 and DC-10. At the time of interviews, these plants were rather slow, to the extent that these plants were doing some sub-contracting machining work on military aircraft parts for the McDonnell Douglas military plant in St. Louis, Mo.

iii) Northrop

Northrop Corporation is reportedly building a substantial section of the F-18A fighter, amounting to about 40% of the airframe. Northrop is responsible for a substantial portion of the $2.91 billion Canadian offset package associated with the CF-18A purchase. This company has expressed considerable interest in

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purchasing machined parts from Canadian sources. Northrop advise they require both 3 and 5-axis N.C. profiling.

c) Central and Eastern U.S.

In the balance of the U.S., the McDonnell Douglas St. Louis, Mo. facility may offer the best market potential, since this company is the prime contractor for the CF-18A and hence responsible for the largest portion of the $2.91 billion offset commitment. The St. Louis plant is the main assembly plant for the F-18A fighter. No contracts had yet been signed at the time of interview concerning outside production in Canada. However, the outside production work being let on the F-18A is for substantial sub-assemblies of the total aircraft. Canadian Aircraft Products Ltd. in Richmond, B.C. advise that they have reviewed the bid packages on this work and consider it beyond their capabilities due to the substantial amount of 5-axis machining required. The only Canadian firms capable of bidding directly on this work are located in eastern Canada.

d) Additional U.S. Markets

Other U.S. aircraft and airframe manufacturers who might be considered to have some market potential, but were not interviewed for this study, are listed below, along with products made and locations of major production facilities.

Name of Corporation	Products Made	Plant Locations
Avco. Corp.	wing assemblies	Tennessee
Bangor Punta Corp.	"Piper" aircraft	Penn., Florida
Cessna Aircraft	aircraft	Kansas
Fairchild Industries	aircraft	N.Y., Md., Tex.
General Dynamics	aircraft	Texas, Calif.
Grumman Corp.	aircraft	New York
Raytheon Co. Inc.	"Beech" aircraft	Kansas
Rockwell International	"Commander" aircraft	Oklahoma
Rockwell International	"North American" aircraft	California
Textron Inc.	"Bell" helicopters	Texas, New York
United Technologies	"Sikorsky" helicopters	Connecticut

e) Canada

In Canada, the two companies building complete aircraft are De Havilland in Toronto and Canadair in Montreal. Both firms have indicated that the distance from B.C. presents a substantial, but not insurmountable, barrier for sub-contract machining work. In view of the fact that both companies are Canadian government owned, and in view of Canada's substantial balance-of-payments deficit with respect to trade with the U.S. on aircraft parts, it is likely that qualified B.C. firms could expect preferential consideration over U.S. firms bidding on the same work, but not over Canadian companies located closer to these plants. Both De Havilland and Canadair are

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bidding on the F-18A sub-sections being sub-contracted to Canadian firms by McDonnell Douglas in St. Louis. It is possible that B.C. shops might have an opportunity to obtain some portions of this work on a sub-sub-contract basis.

The McDonnell Douglas of Canada Ltd. plant in Toronto manufactures wing assemblies for the DC-9 and DC-10 and also the tail emplanage for the DC-9. This plant sub-contracts to qualified Canadian vendors over 8000 different machined parts. This plant is also a bidder for the F-18A sub-section work. Further, McDonnell Douglas of Canada Ltd. may serve as a "clearing-house" for possible additional sub-contract work placed in Canada by McDonnell Douglas of the U.S. in order to meet its offset commitments.

C) Engines

1. General Considerations

The discussion on engines will be abbreviated by simply stating that the machining and processing requirements for most of the parts found in turbine engines are considered to be completely beyond the present, or reasonably foreseeable, machining and finishing capabilities to be found in B.C.

Turbine blades and vanes, and their assembly into stators and rotors is a highly specialized process requiring an enormous investment in specialized tooling and measuring equipment.

Materials are exotics and superalloys (e.g. "Waspalloy") which are exceedingly difficult to machine (carbide or diamond tooling required). Nevertheless, they must be machined to very close tolerances (typically +.0003"-.0000") and to a very smooth surface finish (typically 8 micro-inches). Normal industrial quality machining does not come close to meeting these requirements.

Finishing operations may include shot-peening, heat-treatment, precision grinding, and plating--all to very tightly controlled specifications not available in B.C.

Therefore, we will limit the discussion of machining engine parts to the small percentage of engine parts which could conceivably be made in B.C. These are gears and gear housings.

It should be noted that manufacturers of turbine aero-engines also invariably manufacture stationary industrial turbine engines. A vendor previously unknown to the engine manufacturer is likely to find his first few jobs limited to industrial turbine engines. After he has gained the confidence of the engine manufacturer, he may then be sub-contracted work on aero-engines.

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SPECIFIC MACHINING REQUIREMENTS BY PRODUCT SECTOR (cont.)

2. Machining Requirements, Size and Configurations

Pratt & Whitney Aircraft in Montreal makes a variety of turbine engines classed as "small size". The sizes of components discussed here are based on the Pratt & Whitney components observed. For larger engines, sizes of components may need to be scaled up proportionately from those mentioned here.

Gears range in size from ½ inch to 28 inches in diameter. Gear blanks are of course made by turning--usually on an N.C. lathe. Perhaps the only difference between conventional and aero-engine gears is that the latter have as much unnecessary metal as possible removed by machining--usually by drilling numerous closely spaced holes in zones of surplus metal, such as in webs.

Pratt & Whitney advise that they are not interested in outside production of gear blanks only, but wish to have finished gears manufactured. Therefore, the machine shop doing gear work must have gear tooth cutting capability. Gears are classed as precision gears and may have complex tooth patterns, such as helical or herringbone.

Gear housings are basically bell housings with a variety of drilling, boring, reaming, tapping, contouring and milling operations performed on the surfaces. Such gear housings are generally under 36 inches in their greatest dimension. Such operations are generally performed by 4-axis

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machining centers, but for some configurations, 5-axis machining centers are needed. Generally, only 3-axis contouring capability is required, with additional axes requiring point-to-point control only.

3. Materials Used

Gear materials are generally normal gear steels, supplied either as forgings or as bar stock (to aerospace specifications, of course).

Gear housings are made from either aluminum alloy or magnesium alloy precision investment castings.

4. Tolerances and Surface Finish

Tolerances on these items are not excessively tight, by aerospace industry standards. Gears are cut to typical tolerances of ± .001 inches. Gear housings may have tolerances as loose as ± .005 inches on milled faces, although much tighter tolerances on hole centers and hole diameters are required.

Surface finish in both cases is generally better than for industrial applications for similar products.

5. Finishing Operations

Gears, of course, will require case-hardening and heat-treatment to required specifications by

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qualified facilities.

6. Market Size and Distance

The aero-engine market in the U.S. is quite large--nearly $7 billion in 1979. However, since we have limited the possible production of engine parts in B.C. to only two categories of such parts, the potential size of the market for sub-contract work is very greatly reduced.

In the U.S., there are two major manufacturers of turbine engines--General Electric and the Pratt & Whitney Division of United Technologies. Both of these are located in the north-eastern U.S.

In Canada there are also two manufacturers--Pratt & Whitney and Rolls-Royce--both located in Montreal.

D) Hydraulics

1. General Considerations

The term "hydraulics", as used in this section, refers to the rather specialized haudraulic actuators and related control systems which are used to move aircraft flight control surfaces such as flaps, elevators, etc.

Although small in size, these devices are vital to aircraft safety. Normal working pressure for the hydraulic systems is about 3000 psi.

SPECIFIC MACHINING REQUIREMENTS BY PRODUCT SECTOR (cont.)

The segment of the aerospace industry devoted to "hydraulics" is rather difficult to define, because companies making "hydraulics" usually have other aerospace-related product lines.

2. Materials, Machining Requirements, and Tolerances

There are two basic classes of hardware in actuator hydraulics--the hydraulic cylinder and the control valve assemblies.

Both devices consist of about 50% to 80% aluminum alloy and 20% to 50% steel. Aluminum alloys, which are used for the outer portions of the cylinders and the bodies of the valve asemblies, are supplied either in the form of forgings or as precision investment castings.

Steel is supplied mainly as bar stock and is used for the cylinder piston rods and for internal valve components.

These devices are characterized by: small physical size (greatest dimension is in the range from 2" to 24"); large number of separate parts in a complete assembly; extremely tight dimensional tolerances (down to within ± .00005 inches); and mirror smooth surface finishes on small internal parts.

On parts made from steel, turning is the most common machining operation, although grinding may also be required. On aluminum parts, the

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machining operations performed include turning, drilling, boring, tapping, honing, milling, profiling and contouring.

Most of the above operations are performed on an N.C. machining center. Usually 4 contouring axes are enough, but sometimes a fifth axis is required. It is suggested that a machining center used for this work have a tool changer with a capacity of at least 30 or more tools.

Very little of the most accurate machining is subcontracted. When working to tolerances within ± .00005 inches, a temperature controlled machine shop is advisable to prevent errors due to thermal expansion or contraction of the metal.

3. Finishing Operations and Inspection

Depending on the loading of their own finishing facilities, some manufacturers sub-contract to vendors parts which are to be machined and deburred only. In other cases, parts are required to be completely finished (i.e. anodized, heat-treated, plated, etc.).

It should be noted that because of the very complex geometries and close tolerances of these items, deburring and finishing costs can run as high as 50% of the cost of the part.

Inspection requirements include dimensional checks and sometimes NDT.

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4. Market Size and Distance

The three U.S. companies which we were able to identify as aviation hydraulic manufacturers, namely: Bendix Corp.; Parker-Hannifin Corp. (which includes Bertea Corp.); and the Airesearch Mfg. Co., Div. of Signal Companies Inc.; all have product lines other than aviation hydraulics. A rough estimate of total sales indicates that 1979 sales of the "hydraulics" amounted to less than U.S. $500 million, or less than 1½% of the total U.S. aerospace market.

Plants identified as being manufacturers of aviation hydraulics are located in the Los Angeles, California area and the eastern U.S.

In Canada, the Menasco Div. of Colt Industries Inc. and Héroux Inc., both of Montreal, manufacture aviation hydraulic systems.

E) Landing Gear

1. General Considerations

Landing gear refers to the devices used to absorb the shock of aircraft landing, to support the aircraft on the ground, and to provide directional and braking control when taxiing. Landing gear for larger aircraft invariably retracts after take off, so additional mechanical complexity is required.

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SPECIFIC MACHINING REQUIREMENTS BY PRODUCT SECTOR (cont.)

It is obvious that landing gear is vital to aircraft safety, hence, these devices are made to very high quality standards, and are subject to close inspection, both during manufacture and after installation on the aircraft.

Based on interviews with landing gear manufacturers, it was determined that it was not their general practice to sub-contract machining work on the larger and more critical parts of the landing gear assembly. Rather, smaller and less critical parts were given over to outside production. Hence, this discussion will be concerned with the latter category of parts.

2. Material, Machining Requirements, and Tolerances

Although aluminum continues in use as a landing gear material for some lighter aircraft, larger aircraft and hence the major value of landing gear manufacture is in all-steel landing gear. Steels are used which, when heat-treated, develop ultimate strengths of up to 300,000 pounds per square inch.

Materials are nearly always supplied as forgings.

On parts sub-contracted for outside production, the maximum dimension is generally under 24 inches. There may be some turning and boring required, but the major amount of work is for profiling and contouring in 3, 4 and 5-axis configurations. Contouring and profiling on alloy steel

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rather than aluminum requires a very high spindle horsepower, and high torque at low spindle rotational speed (i.e. a DC-SCR drive system for the spindle motor), for economic machining production.

Tolerances for turning and boring may be as tight as ± .0002 inches, but for contouring and profiling are rarely tighter than ± .002 inches.

3. Finishing Operations and Inspection

For steel landing gear parts, the required post-machining operations are: deburring; sometimes shot-peening; invariably heat-treatment, sometimes followed by grinding; plating by one or more of a wide variety of carefully controlled processes; painting; etc. Generally, post-machining and finishing operations for steel landing gear parts are the most complex and demanding of any category of aerospace sub-systems yet discussed, except for the majority of turbine engine parts.

Similarly, inspection requirements are very rigorous, employing a variety of measurement and NDT techniques.

4. Market Size and Location

The two principal U.S. landing gear manufacturers are: Menasco Inc., subsidiary of Colt Industries Inc.; and Pneumo Corp., which includes Cleveland Pneumatic Tool.

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Sales by these two companies in 1979 totalled about $160 million, or only 0.5% of the total U.S. aerospace market.

Plants of these two companies, in the U.S., are located in California, Texas and the eastern U.S.

In Canada, landing gear is made by Menasco and Héroux in Montreal.

F) Market Potential for B.C. Machine Shops

1. Preface

We will now attempt to provide a qualitative assessment of the aerospace market potential for shops located in southwestern B.C.

We will base the assessment on servicing the market in one of two ways: by performing "outside production" work, or by performing "plant offload" work, as these terms have been used throughout this report.

2. Outside Production

a) Airframe

The market potential is considered good, due to relatively close geographic proximity to large U.S. airframe manufacturers; absence of tariff barriers to aircraft parts; advantageous value of the Canadian dollar for export;

and assurance of a substantial amount of aerospace work being placed in Canada by U.S. firms because of offset agreements. Also favouring this type of work is the absence of requirements for unusually difficult machining skills and the absence of requirements for post-machining operations unavailable locally.

b) Engine

The market potential is considered poor, due to the small fraction of the total number of engine parts which can be made without highly specialized tooling, and the great distance from markets.

c) Hydraulic

The market potential is considered poor, due to the relatively small market size, located at a relatively great distance. Other negative factors include the requirement for machining skills beyond those readily available locally, and the requirement for post-machining operations not readily available locally.

d) Landing Gear

The market potential is considered poor, also due to the small market size, located at a relatively great distance. Another negative factor is the requirement for elaborate post-

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machining operations not available locally.

3. Plant Offload

a) Airframe

The market potential is considered only fair. Distance is a much greater hindrance to obtaining this class of work. The most likely market, the Boeing Company, would offload work to Seattle area shops before considering B.C. shops. Also, the "plant offload" class of work is subject to large swings in demand.

b) Engine, Hydraulic, and Landing Gear

The market for "plant offload" work lies in the range from very poor to non-existent, primarily because of distance.

G) Other Potential Markets

Other potential aerospace markets were identified, but not investigated in depth in the course of this study. All of these are somewhat specialized and located rather distant from B.C. These categories include fuel systems, made by Parker Hannifin and others; electronics made by Hughes Aircraft (Summa Corp.), Ford Motor Co., and others; and engine nacelles made by Rohr Corp. and others. Consult Appendix II-A for additional information.

IX. STATUS OF N.C. MACHINING IN BRITISH COLUMBIA

The use of machine tools in B.C. developed from the need for such services by the large forest products industry, and to a lesser extent by the agriculture and petroleum industries.

Out of a number of these machining facilities developed a number of manufacturing concerns. Today, a number of these are exporting logging and sawmill equipment as well as other specialized products such as pumps, process equipment, etc., on a world-wide basis.

Most of the balance of machine shops in the province are essentially industrial jobbing-shops. There are a few important exceptions. Canadian Aircraft Products Ltd. is a relatively small manufacturer of aircraft parts, including its own line of floats for float planes. This firm does much of its own N.C. machining.

There are, additionally, two relatively small machine shops which have specialized to some degree in aircraft N.C. machining work--namely Decade Industries Ltd. of Richmond, B.C., and CNC Precision Machining Ltd., of North Vancouver, B.C.

ICAM Aerospace Corp. is a proposed facility which intends to specialize in 5-axis N.C. machining of large airframe parts. We have been advised by its proponent that this facility is proceeding, with start-up scheduled for the end of 1981. The plant is to be located somewhere in the Greater Vancouver area, but the exact site has not yet been selected.

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Ebco Industries Ltd. of Richmond, B.C. is also a special case. This company continues as a job-shop for heavy machining, but has also diversified into metal fabrication; production of consumer metal products, such as magnesium wheels, wood-burning stoves, etc.; and computer systems. Ebco is presently reported to be doing some aerospace machining work.

The companies in B.C., which, at the time information for this report was gathered, were known to have N.C. machine tools, either installed or on order, are listed in Appendix III-A.

With the exception of aircraft-oriented shops, the installed N.C. machining capacity in B.C. is heavily weighted towards lathes. This may be considered typical for industrial machining requirements.

After lathes, the next most popular N.C. machine tools in B.C. are machining centers. These are predominantly 3-axis contouring-control machines with single spindles, in a range of size capacities.

In the course of conducting interviews for this study, machine shops were asked to provide information on their present utilization of installed N.C. machine tools. Many shops which cooperated in providing this information nevertheless requested that utilization figures for their particular shop not be published, except as part of an industry average.

For the B.C. Machine Shop Industry as a whole, based on the number of responses received, the average

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percent utilization of N.C. machine tools is roughly 50%. This figure is based on the hours of utilization of the N.C. machine tool divided by the hours that the shop normally works. B.C. machine shops, at the time of interviews, averaged somewhat under 2 shifts working time per 5 day week. From the data received, it was not possible to determine percent utilization for different classes of N.C. machine tools.

However, from the above information, it appears that there is a substantial amount of N.C. machine tool capacity in the province which is not fully utilized.

In the course of conducting interviews for this study, a number of B.C. shops indicated that they were very interested in the aerospace market. Some of these shops are taking definite steps, with respect to quality control systems, in order to solicit aerospace N.C. machining work.

In Appendix III-B, we have listed shops which have indicated a definite interest in aerospace work, along with greater detail concerning their N.C. machine tool capabilities.

X. POTENTIAL PROBLEMS FOR BRITISH COLUMBIA N.C. MACHINING FACILITIES SEEKING AEROSPACE WORK

A) Types of Machine Tools

Although there is a substantial amount of N.C. machining capacity in B.C. which is not fully utilized, much of this consists of machining capabilities which are not in great demand by the aerospace industry. In particular, the aerospace industry has negligible demand for simple turning operations (lathes) or drilling operations (drilling machines, boring mills, or machining centers with point-to-point control).

There is a substantial demand by the aerospace industry for 3-axis contouring and profiling, which can be performed by 3-axis machining centers with contouring-control. However, such work is subject to competitive price bidding. Particularly for smaller-size 3-axis work, there is likely to be competition from firms in other areas with multi-spindle 3-axis contouring and profiling machines. These are likely to underbid firms with single-spindle 3-axis machining centers.

B) Distance from Market

1. Transportation Costs

Due to the relatively high value and relatively light weight of aerospace parts, the transportation cost associated with a single shipment of raw material from, and finished product to the major manufacturer should not affect the landed cost of the product by more than a very small percentage.

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However, if the machined parts need to be moved long distances several times in order to have necessary, qualified processing and finishing work performed, then transportation costs can mount up to the point where competitiveness is lost.

2. Communications between Purchaser and Vendor

In the course of gathering information for this study, it was emphasized many times that close communication links must be maintained between purchaser and vendor.

Distance works against this.

Infrequent communication is acceptable for "outside production" work, since all requirements are well-defined in written specifications.

However, poor communications due to distance are the single biggest reason that B.C. firms should not expect much "plant offload" work.

This "rush" jobbing-type work requires close liaison between the machine shop personnel and production personnel from the major manufacturer.

B.C. firms interested in aerospace work should consider installation of a "telefax" machine in order to receive drawings and sketches quickly by electronic means.

POTENTIAL PROBLEMS FOR BRITISH COLUMBIA N.C. MACHINING FACILITIES SEEKING AEROSPACE WORK (cont.)

Buyers for aerospace corporations advise that periodic personal contact with representatives from vendors is highly recommended.

C) Post-Machining Processing and Finishing Work

Presently available in Vancouver are approved anodizing, painting, and some plating facilities. These are located at Canadian Aircraft Products Ltd. and the CP Air Maintenance Base. We have been advised that these facilities may be made available, at a cost, to machining facilities requiring these services.

We are aware of no aerospace-approved heat-treating facilities available in Vancouver.

There are a number of approved heat-treating and finishing facilities in Seattle which perform jobbing work.

On "outside production" work, finishing is nearly always required. The foregoing tends to favour "outside production" work on aluminum parts, as opposed to steel or some titanium alloys.

D) International Boundary

There are no tariff barriers to the flow of commercial aircraft parts since the last G.A.T.T. agreement was ratified. However, customs declaration forms must be made out correctly for shipments in both

<u>POTENTIAL PROBLEMS FOR BRITISH COLUMBIA N.C. MACHINING FACILITIES SEEKING AEROSPACE WORK (cont.)</u>

directions across the boundary, or else shipment delays may be encountered.

For shipment of military aerospace parts, special licenses may be needed.

E) <u>Personnel - Skills and Training</u>

Machinist training in B.C. is oriented towards skills required by industrial machine shops. The level of quality expected by the aerospace industry is considerably higher. This may require retaining of machine operators for aerospace work.

Quality control personnel familiar with aerospace requirements are in very short supply in B.C. We know of no formal program in this province for training of such personnel. In B.C., the only pools of experience in this field are at Canadian Aircraft Products and CP Air.

Programmers for N.C. machine tools are reported to be in very short supply. Programmers capable of the more difficult programming for 5-axis contouring are in particularly short supply, on a continent-wide basis.

It may be necessary to hire personnel from elsewhere to provide the needed skills and experience in the last two categories. The ammenities B.C. has to offer should make this not excessively expensive or difficult.

XI. RECOMMENDATIONS FOR B.C. SHOPS SEEKING N.C. MACHINING WORK FROM AEROSPACE FIRMS

A) Business Philosophy

We consider that the only reasonable aerospace market, which is able to be served from B.C., is that for finished parts made on an "outside production" basis.

Therefore, a machining facility for aerospace parts should look upon itself as "a manufacturer of finished aerospace parts, made by machining", as opposed to "a machining job-shop doing aerospace work".

B) Quality Control

From information provided so far in this report, it should be obvious that high quality and strict quality control are fundamental to manufacture of aerospace parts.

Industry sources express serious doubts that quality can be adequately controlled in a shop environment where there is a mix of aerospace and industrial parts.

It is considered preferable that aerospace parts manufacture be in a separate area or facility, which can perhaps operate as a division, separate from the parent industrial facility.

In a small operations doing less critical work, some machine tools may be common to both divisions. As a minimum, however, the aerospace division is required to have separate materials storage, accurately

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RECOMMENDATIONS FOR B.C. SHOPS SEEKING N.C. MACHINING WORK FROM AEROSPACE FIRMS (cont.)

calibrated measuring instruments, and cutting tools which are properly calibrated and maintained. Some separate personnel, and a separate work area for operations such as deburring, are also recommended.

C) Marketing

A substantial sales effort will be needed to obtain aerospace business, once quality control requirements are met.

A sales brochure outlining facilities and capabilities of the machine shop is recommended.

Personal contact with buyers and other personnel from aerospace firms is recommended, both initially and at periodic intervals thereafter.

If dealing in far-distant markets, the retention of a marketing representative in the distant area, on a time-shared basis, might be considered.

D) N.C. Machine Tools for Aerospace Work

We will not consider large 5-axis profilers in this discussion, since such specialized, multi-million dollar machines are somewhat outside the scope of this study.

There is relatively little requirement for N.C. lathes by the aerospace industry, except as associated with other complex equipment not available in

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RECOMMENDATIONS FOR B.C. SHOPS SEEKING N.C. MACHINING WORK FROM AEROSPACE FIRMS (cont.)

B.C. The small requirement for turning which does exist will likely be satisfied by facilities located in close proximity to principal aerospace manufacturers.

The greatest demand for machine tools of less than 5-axis capability is for 3 and 4-axis contouring and profiling machines. The larger the machine, generally, the greater the demand.

While there is quite a large amount of work available for small 3-axis profilers, there are many such machines, so bidding on such work will be highly competitive.

For 3-axis profiling and contouring, more competitive pricing will be achieved using multi-spindle machines.

For smaller single-spindle 3 and 4-axis machines, the more versatile machining centers should be considered in preference to simple profilers and milling machines.

A modern machine tool controller with CNC capabilities is both easier to program and has added features which improve productivity over older-type controllers without CNC features.

If machining of aerospace materials other than aluminum is to be considered, a DC-SCR spindle drive system of high horsepower is recommended. For high accuracy machining, the machine tool must be structur-

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ally very rigid and free from backlash.

E) Overhead

Notwithstanding the foregoing discussion, a shop seeking to be successful in aerospace machining on "outside production" requirements should have both high productivity and low overhead costs.

"Outside production" work is invariably subject to competitive bidding, frequently on a continent-wide basis. The low bidder is usually the successful bidder.

F) Recommended Markets

We consider the best market to be in the airframe sector. Therefore, the machine shop will be dealing with a principal aerospace manufacturer or a major sub-contractor for airframe parts.

Generally, the closer the purchaser, the better chance the seller has of getting work.

In the Greater Vancouver area, Canadian Aircraft Products is presently sub-contracting some machining work to other local firms.

After the ICAM facility commences business, it should be a good source of work for smaller firms. Because of amortization and overhead costs, ICAM could not possibly afford to tie up its costly, large 5-axis

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RECOMMENDATIONS FOR B.C. SHOPS SEEKING N.C. MACHINING WORK FROM AEROSPACE FIRMS (cont.)

machines on small 3-axis work. ICAM fully intends to sub-contract such work to local firms. However, the volume of sub-contract work exchanged between local firms is likely to remain relatively small.

From the point-of-view of shops located in southwestern B.C., the best market is the enormous Boeing facilities in Seattle. This company operates many groups and divisions, each with separate purchasing authority. Therefore, there are a large number of potentially large customers in this one corporate giant.

We rate the medium-distant California market about equal with the farther distant Canadian market as being the next best potential market. Some firms in both areas have reasons for "buying Canadian" at this time.

The central and eastern U.S. has the least potential for purchases directly from B.C. firms at this time.

XII. CONCLUSIONS

A) The Aerospace Industry - General

1. Although the aerospace industry is subject to short-term fluctuations in business activity, due to both economic and political factors, the long-term prospects for the industry appear to be for substantial, steady growth.

2. It is common practice for firms within the aerospace industry to sub-contract manufacturing work to other firms within the industry. Therefore, it is rare to find one firm who is extremely short of manufacturing capacity at the same time that another firm has a great surplus of capacity. As a consequence, the aerospace industry, as a whole, tends to become busy or slow as market conditions dictate.

3. Any discussion concerning the aerospace industry would not be complete without the recognition that this industry encompasses the very forefront of technological change. This includes the fields of mechanical design, materials science, computer programming skills, and the machinist's art. Hence, there is ample opportunity for clever innovation in all of these areas. The aerospace industry has a history of rewarding very handsomely those groups and individuals who develop ingenious prducts, techniques, and solutions to problems.

   The other aspect of the rapid pace of technological change within the aerospace industry is that manufacturing techniques and business opportunities within the industry are likely to change, in rela-

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tively few years, in a way which is completely unpredictable at this time

B. The Potential Market for Aerospace Machining-Related to British Columbia.

1. It had earlier been suggested that the aerospace industry, as a whole, was short of N.C. machining capacity of all types. As of late summer, 1980, there was found to be little or no shortage of N.C. machining capacity with respect to N.C. lathes or 3 and 4-axis N.C. profiling and milling machines.

2. In spite of the above, there exist, at this time, reasons to indicate that a company, located in B.C., which is dedicated to the manufacture of machined, finished airframe parts, stands a good chance of success.

The reasons, which did not exist several years ago, are as follows:

a) the elimination of customs duty on commercial aircraft parts.

b) the low value of the Canadian dollar, relative to the U.S. dollar, which favours Canadian exports.

c) a substantial amount of aircraft parts manufacture will be done in Canada over the next 15 years, due to recently negotiated trade offset agreements with U.S. aerospace manufacturers.

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CONCLUSIONS (cont.)

3. An attempt by a machine shop, located in B.C., to obtain a substantial amount of work from the aerospace industry on the basis of being a "job-shop for N.C. machining" is less likely to be successful than that of obtaining work on the basis of being a "manufacturer of machined, finished aircraft parts".

4. Although there are a number of potential markets for B.C. aerospace manufacturers, the Boeing company and its many divisions in the Seattle area is considered to be the best market prospect because of its sheer size and relatively close geographic proximity.

   After Boeing, aerospace firms located in eastern Canada and in southern California appear to offer the next-best market potential.

C. The Present Aerospace Machining Capabilities of B.C. Industry.

1. There presently exists, in B.C., a substantial amount of surplus N.C. machine tool capacity. However, most of the surplus machine tool capacity available in B.C. is either not in demand by the aerospace industry or else is unlikely to be price-competitive within the present aerospace market.

2. Limited facilities are presently in existence in B.C. for post-machining finishing operations which are necessary for aircraft parts made from aluminum alloys. For aerospace parts made from other metals,

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there appears to be a shortage or absence of suitable processing and finishing capabilities within the province.

3. In B.C., at present, there is no large pool of the skills and expertise which are necessary to manufacture aircraft parts by N.C. machining. Aerospace quality control and N.C. machine tool programming are skills which appear to be in particularly short supply. Also, aerospace machining is generally more demanding than industrial machining. Therefore, a certain amount of upgrading of the skills of machinists may be necessary for aerospace work.

D. Summary of Recommendations for B.C. Companies Seeking to Become Manufacturers of Machined Aerospace Components.

1. There are a great variety of categories of parts used on aircraft. Of the categories investigated, airframe parts made from aluminum alloys appear to be the products best suited to conditions prevailing in B.C. at this time.

2. A company considering the purchase of new N.C. machine tools to manufacture airframe parts should select contouring and profiling machines or machining centers, with contouring control of 3 or more axes, in preference to other types of equipment.

   Modern CNC-type controllers are preferred. Likewise, machines of large physical size and with multiple-spindles are preferred.

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CONCLUSIONS (cont.)

On smaller, single-spindle machines, machining centers are more useful than simple profilers.

3. A company which has only single-spindle 3 or 4-axis machines of relatively small physical size will encounter stiff price-competition for aerospace work. Therefore, such companies will need to maintain high productivity and low overhead costs in order to be successful.

4. A B.C. company seeking to become a manufacturer of aerospace parts will need to make a substantial investment in personnel skills and marketing effort, in addition to any investment in machine tools and facilities.

5. A. B.C. machining company which intends to do business with major aerospace manufacturers should follow marketing and business practices which are recommended by the industry.

   A summary of these is as follows:

   Production of parts to consistently high quality standards is fundamental to the industry. Any firm seeking to do business with the aerospace industry must have established adequate quality control and inspection systems.

   A firm soliciting business for the first time from a major aerospace manufacturer should:

   a) be familiar with that manufacturer's

quality standards, and be capable of meeting these.

b) have prepared a written brochure describing itself, its machining facilities and other capabilities.

c) have information available on its credit, working capital, and present level of machine tool utilization.

d) make advance appointments and have a representative make personal visits to many individual buyers within the major manufacturing company.

e) concentrate its efforts on divisions of major aerospace manufacturers which are in the early stages of new building programs.

f) periodically keep in touch with buyers who indicate the possibility of forthcoming work.

g) be patient, since it is possible for many months to elapse between initial visits to buyers and receipt of a request for quotation on machined parts within the vendor's capabilities.

After receiving a request for quotation, the machining firm should respond promptly, either with a quotation or a reply which states a valid reason why it is unable to quote.

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CONCLUSIONS (cont.)

If the machining firm is an unsuccessful bidder on a particular quotation, it should contact the buyer responsible to determine reasons for its lack of success.

In order to obtain repeat business, a machining firm must produce parts of acceptable quality with all necessary documentation in order. Delivery must be on schedule, unless prior arrangements are made with the buyer, due to exceptional circumstances.

APPENDIX I - EXAMPLES OF AEROSPACE QUALITY CONTROL REQUIREMENTS

Appendix I-A - "Supplier Quality System Requirements--Level III" - The Boeing Company - Form D1-4803-0353 (Rev. 6/78).

Appendix I-B - "Supplier Quality System Requirements--Level II" - The Boeing Company - Form D1-4803-0352 (Rev. 6/78).

Appendix I-C - "Minimum Vendor Capabilities for: Cl.IV - Less Complex Machined Parts" - Pratt & Whitney Aircraft du Canada Ltée. - 18 April 1979.

Appendix I-D - "Minimum Vendor Capabilities for: Cl.III - Medium Complex Machined Parts" - Pratt & Whitney Aircraft du Canada Ltée. - 18 April 1979.

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The Boeing Company
SUPPLIER QUALITY SYSTEM REQUIREMENTS
LEVEL III
Form D1 4803 0353 (Rev. 6/78)

1.0 GENERAL

1.1 Seller shall establish and maintain a quality system in accordance with this requirement. This system shall be subject to Buyer's periodic evaluation and verification.

1.2 Requirements specified herein are less stringent than those contained within D1 4803 0351 or D1 4803 0352.

1.3 Seller may elect to implement the requirements contained within D1 4803 0351 or D1 4803 0352, without further action, if Seller's quality system has been approved by Buyer in writing, as being in compliance with such forms, provided there is no additional cost to Buyer.

2.0 QUALITY PROGRAM PLAN

2.1 Seller shall maintain documentation which defines the quality system to be used during the period of contract performance. This documentation shall be in narrative form, contain, as a minimum, the requirements listed below, and be available for Buyer review at any reasonable time during period of contract performance.

a. Organizational Structure

Define the Seller's quality control organization; include charts depicting Seller's management and quality control organization.

b. Quality Control Procedures Defining:

1. Drawing and specification control.
2. Purchased material control.
3. Measuring and test equipment control.
4. Manufacturing and process control.
5. Product acceptance.
6. Nonconforming material control.
7. Material control.
8. Sampling inspection.
9. Records retention.

c. Manufacturing and Inspection Flow:

A manufacturing flow diagram shall be maintained to depict the complete manufacturing cycle, including processing and inspection points.

3.0 DRAWINGS AND CHANGES

Seller shall not make any change in materials or design details which would affect the part or any component part thereof with regard to (a) part number identification, (b) physical or functional interchangeability, and (c) repair and overhaul procedures and processes and material changes which affect these procedures, without prior approval of Buyer, and without revising the part numbers and the originals of all drawings or data affected by the change. Copies of the revised drawings or data shall be forwarded to Buyer.

Seller shall insert this clause in all subcontracts for supplier identified purchased equipment whether such equipment is supplied to Seller as an end item or as a component part of an end item.

4.0 **PROCESS CONTROL**

Seller shall use processors listed in Buyer document D1-4426, Boeing Approved Process Sources, when any process listed in that document is specified in Buyer's detailed design drawing. Production in accordance with Buyer's specification control drawing or source control drawing requires use of Buyer-approved processors only when Buyer's process specification is listed in the specification or source control drawing. The packing sheet accompanying each shipment must reference the name of the processor who accomplished the processing in accordance with D1-4426. Buyer approval of any process source shall not relieve Seller of Seller's obligation and liabilities under this contract.

4.1 **SHIPPING**

Packing sheets shall identify the latest change or revision level and the serial number(s) of items being shipped.

5.0 **NONCONFORMING MATERIAL CONTROL**

5.1 All nonconforming supplies shall be identified to prevent use, intermingling with conforming supplies, or shipment. Holding areas shall be provided.

5.2 Seller dispositions of nonconforming materials are limited to the following:

a. Rework-to-drawing

b. Scrap

c. Return-to-supplier

5.3 If the nonconformance cannot be processed within the limits of 5.2, or if any degree of doubt exists, it shall be submitted to the Buyer for disposition.

5.4 Shipment of Buyer-dispositioned nonconforming material shall be accomplished separately from acceptable material. The shipping paper shall reflect the Buyer's nonconformance form number. If available at time of shipment, a copy of the nonconformance form shall be attached to the hardware or shipper. Nonconforming articles will not be shipped prior to receipt of Buyer's disposition unless specifically authorized by written communication. When Buyer's source inspection and acceptance is a requirement of the purchase contract, copies of all nonconformance forms, records, and related correspondence will be provided to the Buyer's quality assurance representative at the time hardware is presented for acceptance.

6.0 **CORRECTIVE ACTION**

Seller shall, on request, on forms designated by Buyer, provide statements of corrective action on Seller's hardware rejected by Buyer. Corrective action statements, at Buyer's option, may require approval signature by Buyer and Buyer's Customer quality representatives. All rejected articles resubmitted by Seller to Buyer shall bear adequate identification, including reference to Buyer's rejection document.

7.0 **SAMPLING INSPECTION**

Sampling plans used for acceptance of material, parts, or processes, shall be documented and submitted for Buyer approval no later than 30 days after receipt of the purchase contract. While the plans are being initially evaluated, Seller may continue to use his published statistical plan provided it conforms with MIL-STD-105, or other military sampling standards. Any sampling plan used shall provide valid confidence and quality levels.

8.0 **BUYER'S EVALUATION**

Seller's quality system is subject to periodic evaluation and verification by Buyer's quality assurance representative. Buyer may elect to verify the quality of work and materials, at any place, including the plants of any of Seller subtier suppliers and at any production state, of materials intended for incorporation into Buyer's products. Such investigations at subtier facilities will be requested through the

Seller's inspection function and performed jointly with the Seller.

9.0 QUALIFIED PRODUCTS

The inclusion of products from Qualified Products Lists (QPL) does not relieve Seller of his responsibility for providing supplies which meet all specification requirements nor for performing the inspections and tests specified for such materials.

The Boeing Company

SUPPLIER QUALITY SYSTEM REQUIREMENTS
LEVEL II

Form D1 4803 0352 (Rev. 6/78)

1.0 GENERAL

1.1 Seller shall establish and maintain an Inspection System in accordance with this requirement. This system shall be subject to Buyer's periodic evaluation and verification.

1.2 Requirements specified herein are less stringent than those contained within D1 4803 0351, but more stringent than those contained in D1 4803 0353.

1.3 Seller may elect to implement the requirements contained within D1 4803 0351, without further action if Seller's quality assurance system has been approved by Buyer in writing as being in compliance with D1 4803 0351, provided there is no additional cost to Buyer.

2.0 PROCEDURES

2.1 Seller shall establish and maintain written procedures which define his inspection system. These procedures are subject to Buyer's right of disapproval and shall include, but not be limited to, the following:

a. Quality control organization's responsibility for the inspection system.

b. Inspection and testing instructions which assure inspection and test of materials, work in process, and completed articles. Instructions shall be complete, clear, and current and shall include accept/reject criteria.

c. Adequate records of all inspections and tests performed which indicate the nature and number of observations made, the number and type of deficiencies found, the quantities approved or rejected, and the corrective action taken.

d. Prompt action to correct assignable conditions which have or could result in delivery of nonconforming articles or services.

e. Calibration/certification control of measuring and test equipment to assure continued accuracy and traceability to authorized primary standards.

f. A positive system for identifying the inspection status of articles whether by stamps, tags, routing cards, move tickets, or other control devices.

g. Copies of all forms and other record media used to record the quality status of products.

h. Methods used to control issuance and use of parts, materials, etc., with specific controls of age-limited items.

i. Other requirements, i.e., tooling controls, data submittals, etc., as imposed by specification or contract.

3.0 DRAWINGS AND CHANGES

3.1 Seller shall maintain a system which assures only the latest applicable drawings, specifications, and instructions required by the purchase contract are used for receiving, fabrication, inspection, test, packaging, and shipping.

3.2 Seller shall not make any change in materials or design details which would affect the part or any component part thereof with regard to (a) part number identification, (b) physical or functional interchangeability, and (c) repair and overhaul procedures and processes and material changes which affect these procedures, without prior approval of Buyer, and without revising the part numbers and the originals of all drawings or data affected by the change. Copies of the revised drawings or data shall be forwarded to Buyer.

Seller shall insert this clause in all subcontracts for supplier identified purchased equipment whether such equipment is supplied to Seller as an end item or as a component part of an end item.

4.0 RECEIVING INSPECTION

Seller shall perform the necessary inspections or tests to assure subcontracted or purchased supplies meet contract requirements. Any nonconformances found on government source inspection articles shall be reported to the government representative.

5.0 PROCESS CONTROL

a. Seller shall have as an integral part of the inspection system, procedures for the control of those processes required by specification or contract.

b. Seller shall use processors listed in Buyer document D1 4426, Boeing Approved Process Sources, when any process listed in that document is specified in Buyer's detailed design drawing. Production in accordance with Buyer's specification control drawing or source control drawing requires use of Buyer-approved processors only when Buyer's process specification is listed in the specification or source control drawing. The packing sheet accompanying each shipment shall reference the name of the processor who accomplished the processing in accordance with D1-4426. Buyer approval of any process source shall not relieve Seller of Seller's obligation and liabilities under this contract.

c. Seller's system shall provide and enforce procedures for the proper inspection of shipments for completeness of manufacture, and to assure that shipments meet all requirements for marking, packing and packaging, and for the presence of properly completed packing sheets. Packing sheets shall identify the latest change or revision level and the serial number(s) of items being shipped.

6.0 NONCONFORMING MATERIAL CONTROL

6.1 Refer to Section 11.0 for definitions applicable to Section 6.0

6.2 Material found to depart from requirements shall be appropriately identified by a serialized nonconformance form, diverted from normal production channels, and routed to an area designed to prevent its unauthorized use, shipment, or inter-mingling with acceptable material. Material which cannot be routed to a controlled area for such reasons as size or environmental restrictions shall be placed in an area in which the Seller's inspection organization has the ability to maintain control of the nonconforming materials.

6.3 When material is initially found to be nonconforming, the following preliminary review action may be taken but not exceeded by Seller's quality inspection material review representative without referral to a full MRB.

a. Provide detailed rework instructions on the rejection form to correct a nonconformance to drawing configuration by adjustment, completion of work omissions, or removal and replacement of parts and assemblies.

b. Assign scrap dispositions for Seller's materials which are obviously unfit for use or not economically reparable.

c. Assign return to supplier disposition.

d. Provide predisposition instructions, such as fault isolation or failure analysis.

6.4 If the nonconformance cannot be processed within the limits of the above preliminary review actions, or if any degree of doubt exists, it shall be referred to a Material Review Board for disposition.

6.5 Seller shall not convene his Material Review Board for nonconforming articles to be delivered on Buyer's contracts until Buyer's written authorization is obtained. To obtain Buyer authorization, Seller shall submit procedures for control of nonconforming materials and the qualifications of Material Review Board personnel to the Buyer. These data shall include resumes of education, training, and experience for each proposed Material Review Board representative and organization charts indicating the representative's position within the organizational structure. The Buyer reserves the right of selective disapproval of both procedures and personnel. Buyer will respond to Seller in writing, defining the conditions and limitations of Seller's material Review Board authority. Proposed revisions to approved nonconforming material control procedures, and changes to authorized Material Review Board personnel, shall be submitted to Buyer for approval prior to implementation.

6.6 Preliminary Review and Material Review Board authority shall not be delegated to lower tier suppliers without prior authorization by the Buyer.

6.7 If the Seller has been delegated MRB authority, Seller's Material Review Board may:

a. Provide repair disposition instructions.

b. Determine that the nonconformance is of minor significance and is usable without correction.

All "use as is" dispositions shall include rationale and justification for such dispositions and a determination of the appropriateness for design or documentation changes.

c. Provide rework dispositions.

d. Provide return to supplier dispositions.

6.8 All nonconformances outside the scope of Seller's MRB authority (i.e., the nonconformance affects functional performance, interchangeability, reliability, maintainability, weight, effective use or operation, appearance (where a factor), health and safety, durability or provisions of the Buyer's design control specification) shall be submitted to the Buyer for disposition. The submittal will include the part number of the article, the purchase contract number, the number of units affected, a complete description of the nonconformance, including the design requirement and tolerances affected, all drawing and specification references, recommended disposition or fix, cause, corrective action, effectivity of corrective action by serial number or date, and name of the Seller's representative responsible for corrective action.

6.9 Whenever publications such as drawings, documents, or process specifications are available to provide detailed work instructions, the publications shall be identified in the dispositions. When such documentation is not available, the disposition must specify, as a minimum, appropriate processing instructions, required materials, and acceptance criteria.

6.10 Material review personnel shall evaluate each situation to determine the level of detail required and shall withhold disposition approval if the work instructions are not adequate.

6.11 Material review personnel shall, when determining dispositions for nonconformances, determine the need for reinspection of similar materials and units in process, and completed units at other plant locations or delivered to customers.

6.12 Material which has received a disposition of "scrap" shall be permanently identified. The requirement for permanent scrap identification shall take precedence over any post-scrap utility consideration.

6.13 Any disposition of customer property (Government or Buyer property) furnished in relation to Buyer contracts requires authorization by the Buyer, or as otherwise provided in the contract.

6.14 Material Review Board dispositions shall not be used in lieu of planned engineering design changes.

6.15 Shipment of Buyer-dispositioned nonconforming material shall be accomplished separately from acceptable material. The shipping paper shall reflect the Buyer's nonconformance form number. If available at time of shipment, a copy of the nonconformance form shall be attached to the hardware or shipper. Nonconforming articles will not be shipped prior to receipt of Buyer's disposition unless specifically authorized by written communication. When Buyer's source inspection and acceptance is a requirement of the purchase contract, copies of all nonconformance forms, records, and related correspondence will be provided to the Buyer's quality assurance representative at the time hardware is presented for acceptance.

Corrective action to prevent recurrence of nonconformances shall be taken on materials manufactured or procured by Seller.

Corrective actions shall be extended to the performance of all lower-tier suppliers and shall be responsive to data and nonconforming hardware forwarded from customers and other using organizations.

Seller material review personnel shall have the authority and responsibility to withhold further processing when not satisfied that effective corrective action measures are being taken.

Corrective action shall include, as a minimum:

a. Analysis of data and examination of nonconforming articles to determine the extent and cause of the nonconformance.

b. Introduction of timely and effective corrective action to prevent recurrence.

c. Effectivity of corrective action by serial number, calendar date, or specific event.

d. Signature of the individual responsible for the corrective action.

e. Signature of the material review representative who confirms the adequacy of the corrective action.

6.16 Buyer and government representatives shall be provided with continuous visibility of the overall nonconformance date and effectiveness of corrective action being taken.

6.17 Seller shall, on request, on forms designated by Buyer, provide statements of corrective action on Seller's hardware rejected by Buyer. Corrective action statements, at Buyer's option, may require approval signature by Buyer and Government quality representatives. All rejected articles resubmitted by Seller to Buyer shall bear adequate identification, including reference to Buyer's rejection document.

7.0 SAMPLING INSPECTION

7.1 Statistical inspection applications, including sampling plans and statistical process controls used in the acceptance of materials or parts or processes, shall be documented and submitted to Buyer for approval no later than 30 days after receipt of the initial purchase contract. The documentation shall define which plans are to be used in specific areas of Seller's activities (e.g., receiving inspection, fabrication, and subassembly) and instructions establishing inspection levels, AQL's, etc.

7.2 Seller may elect to submit a statement that 100% inspection will be accomplished on all articles produced for this contract, or utilize statistical sampling inspection procedures as provided below.

Statistical procedure submittal is not required, however, when the Seller has on file a copy of Buyer's correspondence approving the current revision of the statistical procedures.

7.3 While plans are being initially evaluated, Seller may continue to use his published statistical plan provided it conforms with MIL-STD-105 or other military sampling standards. Any sampling plan used shall provide valid confidence and quality levels.

7.4 MIL-Handbook-53, "Guide for Sampling Inspection," may be used as a quide in establishing a statistically valid sampling system acceptable to the Buyer.

7.5 If Seller's statistical inspection documentation is disapproved, he is required to perform 100% inspection on Buyer's products until the deficiencies are eliminated and the revised documentation is approved. Exceptions shall be negotiated with Buyer on an individual basis.

8.0 CUSTOMER FURNISHED MATERIAL

Seller shall maintain procedures for control of customer (Government or Buyer) furnished property, equipment and/or materials which shall include as a minimum:

a. Receiving inspection to determine in-transit damage, completeness, proper type, functional testing, identification and verification of quantity.

b. Periodic inspection and precautions to assure adequate storage conditions and to guard against damage from handling and deterioration during storage.

c. Control of nonconforming or damaged customer furnished materials.

9.0 BUYER EVALUATION

Seller's quality system is subject to periodic evaluation and verification by Buyer's quality assurance representative. Buyer may elect to verify the quality of work and materials, at any place, including the plants of any of Seller subtier suppliers and at any production state, of materials intended for incorporation into Buyer's products. Such investigations at subtier facilities will be requested through the Seller's inspection function and performed jointly with the Seller.

10.0 QUALIFIED PRODUCTS

The inclusion of products from Qualified Products Lists (QPL) does not relieve Seller of his responsibility for providing supplies which meet all specification requirements nor for performing the inspections and tests specified for such materials.

11.0 DEFINITIONS

The following definitions apply to this requirement:

11.1 Nonconforming Material: Any item, part, or product with one or more characteristics which depart from the requirements in the contract, specification, drawing, or other approved product description.

11.2 Major Nonconformance: A nonconformance which cannot be completely eliminated by rework or reduced to a minor nonconformance by repair. Final decision for acceptance of material containing major nonconformances is made by the Buyer.

11.3 Minor Nonconformance: A nonconformance to the requirements specified in the contract, specification, drawing or other approved product description which does not adversely affect:

a. Performance

b. Durability

c. Reliability

d. Interchangeability

e. Effective use or operation

f. Weight or appearance (where a factor)

g. Health or safety.

11.4 Preliminary Review (PR) Action: The action taken by Seller appointed quality personnel when a nonconformance is found and referral to the Material Review Board for disposition is not warranted.

11.5 Material Review Board (MRB): A Seller board consisting of representatives of Seller's organizations necessary to disposition nonconforming material referred to them.

a. The MRB is to be chaired by a representative of the Seller's quality organization and includes, as required, personnel representing other Seller organizations necessary to determine appropriate disposition for nonconforming material. As a minimum, the MRB includes the chairman and one representative of the Seller's engineering organization responsible for product design. Buyer's customer representative shall be considered a member of the Seller's MRB.

b. MRB members are selected on the basis of their technical competence and their knowledge of their MRB procedures. MRB members may call upon other Seller personnel for technical advice.

c. If warranted by the volume of nonconforming material or the diversity of work operations, more than one MRB may be established.

11.6 Reworked material: Material that was nonconforming but has been subjected to a process that restores all nonconforming characteristics to the requirements in the contract, specification, drawing, or other approved product description.

11.7 Scrap: Nonconforming material that is not usable and cannot be economically reworked or repaired.

11.8 "Use As Is" Material: Material with minor nonconformances presented by the Seller and accepted by the Buyer's customer representative when the material is determined to be satisfactory for its intended purpose.

11.9 Repaired Material: Nonconforming material subjected to a process designed to reduce but not completely eliminate the nonconformance.

11.10 Occurrence: The first time a nonconformance is detected on a specific characteristic of a part or process. All nonconformances attributed to the same cause and indentified before the date, item, unit, lot number or other specified commitment for effective corrective action are also considered occurrences.

11.11 Recurrence: A repeat of nonconformance other than provided for in 11.10.

MINIMUM - VENDOR CAPABILITIES FOR: CL.IV-LESS COMPLEX MACHINED PARTS

Examples: Covers, Fittings, Washers, Bosses in Aluminum and SST
i.e. simple configuration, turned, milled, drilled; Tol ± .001 & 63 √ FIN.

Resources Necessary: Plant - fair integration of layout & 300 sq.'/Production Employee

Personnel: Basic technology necessary tied into possible previous aircraft structure subcontract work
Ratio of skilled to none skilled: 1:2

Note: Technological resource must be inherent in either Personnel or Equipment sophistication

Equipment: Conventional Equipment - Invest/Prod. Employee: $15,000 - 20,000

Includes:
Lathes, Turrets
Horiz. & Vert. Milling
Drill press; possible turret drill
Possible surface grinding
Deburring Dept.: hand tools

Tooling: Design & make good quality
If tools made in plant, Tool Room can be integral with plant

Quality:
Systems
Must have basic Q.C. Manual on Quality Management
Planning and Control
Must have gage calibration

Q.C. Room
Must have basic equipment
Mikes Vernier,
Height gage surface plate

Must have bonded storage for (a) R/M (coded) (b) deviating material
Ratio of Q.C. Personnel (fulltime) to Production Persons 1:15

Finance: Adequate financial strength; positive net worth
i.e. Adequate working capital/funds position
Adequate debt/ownership leverage

Note: Adequate = Average for the industry at vendor's level of operation

Managerial:
Planning: basic short to med. term
Organizing: good systems
Controlling: follow systems
Motivating: good labor relations
Auditing: history record avail.

Gen: some form of budget control

Technology:
Systems: 1) Process Planning
Min.: MOS sheet (master operation sheet) could combine as travel card
2) Estimating & Pricing: basic techniques
Rates $15 - 17/hr.
3) Production Control: Manual control with some plan

General: Shop should show an orderly arrangement of business structure & have some technological exposure, possibly 3 - 5 years.
Manpower: Min 6 - 12 to justify systems necessary.

P&WC Support: Sample Q.C. Manual and vendor development through gradual start-up

Prepared by: G.P. Jonnson
18 April 1979

[signature]

PRATT & WHITNEY AIRCRAFT DU CANADA LTEE.
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MINIMUM VENDOR CAPABILITIES FOR: CL III - MEDIUM COMPLEX MACHINED PARTS

Examples: Small hsg's, Hardware, Minor Valves, Guides & Rings in Steels - carb. & Lo-Alloy, Aluminum, magnesium and SST i.e. parts turned, milled, drilled, tapped or threaded, possibly ground OD & ID or surface with some contour; Tol ± .0005 & 32 Fin.

Resources Necessary: Plant - good integration of layout & 350 - 400 sq. '/ Production employee

Personnel: Fair to good technology necessary having previously done aircraft structural components
Ratio of skilled to non skilled: 1:1

Note: Technology rsources must be inherent in both personnel and equipment sophistication

Equipment: Conventional & some advanced equipment. Ave. age not over 12 yrs. Investment/Production employee $20,000 - 30,000

Includes: Lathes, turrets, chuckers if necessary: Automatics
Milling: Horiz., Vert. possibly profilers & NC machining centers
Drilling: Dr. Press, Turret Dr., Multi spindle
Grinding: Universal & surface possibly thread grd.
Deburring Dept: hand tools, sanders, vacuum blast

Tooling: Design & make - good quality possibly separate room with layout facility. However, could be integ. with plant

Good inspection of tools

Quality: Systems
Well planned Q.C. Manual on Q.C. management, planning & control must have gage calibration

Q.C. Room
Mikes, verniers, height gauge, surface plate, sine bar/plate & Jo-blocks, profilometer, plug, ring & thd. gages

Must have bonded storage for (a) R/M (coded) (b) deviating parts
Ratio of Q.C. personnel (full-time) to Prod. persons 1:12

Finance: good financial strength to support systems
i.e. positive net worth and profitability
good working capital/funds position
good debt/ownership leverage

Note: Comparisons will be made to Industry average for level of operation

Managerial:

Planning:	well planned med-long term
Organizing:	good systems
Controlling:	close control of systems
Motivating:	good labour relations
Auditing:	adequate history record avail.
General:	definite control of budget

Technology:
Systems: 1) process planning to part complex. incl. O.P. ops & control. MOS sheet & travel card combo
2) Est'g & Pricing: Std's predetermined & controlled. Rates: $16 - 22/Hr.
3) Prod. Ctr.: well defined Plan & F/U could be manual ctr. rel. to Prod.

General: Must show an orderly arrangement of business structure & controls along with definite aircraft technology experience, although still not airborne engines. Possibly 5-10 years; manpower 12 - 20 so as to justify systems necessary.

P&WC Support: Constant monitoring of performance & relative upgrading

Prepared by: G.P. Jonnson
18 April 1979

Jonnson

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Appendix II-A - Major Corporations in the U.S. Aerospace Industry

(Names of major subsidiaries or well-known trade names are shown in brackets.)

Name of Corporation	Principal Products	Location of Production Plants	Total 1979 Sales of Aerospace Products (Millions of U.S. $)
1. Avco Corp.	aircraft wings, (incl. airframe) engine parts	Tennessee Connecticut	496.1
2. Bangor Punta Corp. (Piper Aircraft)	light aircraft (incl. airframe)	California Pennsylvania Florida	336.8
3. Bendix Corp.	hydraulics, miscellaneous	New York Michigan California Indiana	159.7
4. Boeing Co.	aircraft (incl. airframe)	Washington Kansas Alabama Pennsylvania Utah Oregon New Mexico	4,478.4

Appendix II-A (cont.)

Name of Corporation	Principal Products	Location of Production Plants	Total 1979 Sales of Aerospace Products (Millions of U.S. $)
5. Cessna Aircraft Commercial	light aircraft (incl. airframe)	Kansas Ohio New Jersey	696.1
6. City Investing (Hayes International Corp.)	aircraft	Alabama	172.0
7. Colt Industries (Menasco Mfg. Co. Inc.) (Chandler Evans Inc.)	landing gear engine parts	California Texas Connecticut	148.9
8. E-Systems Inc.	miscellaneous	Texas Utah South Carolina	179.1
9. Ex-Cello Corp.	miscellaneous	Connecticut Ohio Michigan Indiana New Jersey	255.4

Appendix II-A (cont.)

Name of Corporation	Principal Products	Location of Production Plants	Total 1979 Sales of Aerospace Products (Millions of U.S. $)
10. Fairchild Industries Inc. (Fairchild Republic Co.)	aircraft (incl. airframe)	New York Maryland Texas Florida California	578.7
11. Fruehauf Corp. (Kelsey Hayes Co.)	engine parts, aircraft machined parts	New York Ohio	143.8
12. General Dynamics Corp.	aircraft (incl. airframe)	Texas California	901.5
13. General Electric Co.	engines, engine parts	Ohio Massachusetts Vermont New Hampshire Idaho Kansas New Mexico	1,323.6

Name of Corporation	Principal Products	Location of Production Plants	Total 1979 Sales of Aerospace Products (Millions of U.S. $)
14. General Motors Corp. (Allison)	engines, engine parts	Indiana	166.2
15. Goodyear Tire & Rubber (Goodyear Aerospace Corp.)	rubber products, fuel systems	Ohio	170.1
16. Grumman Corp.	aircraft (incl. airframe)	New York Georgia Maryland Florida Washington	856.8
17. Hercules Inc.	rocket engines, rocket fuels, explosives	Utah West Virginia	198.3

Appendix II-A (cont.)

Name of Corporation	Principal Products	Location of Production Plants	Total 1979 Sales of Aerospace Products (Millions of U.S. $)
18. Lockheed Corp.	aircraft (incl. airframe)	California Georgia Arizona Texas South Carolina Mississippi West Virginia	2,105.5
19. LTV Corp. (Vought Corp.)	airframe parts, miscellaneous	Texas Michigan	249.3
20. McDonnell Douglas Corp.	aircraft (incl. airframe	Missouri California Oklahoma	3,504.4
21. Northrop Corp.	aircraft (incl. airframe)	California Oklahoma	741.7

Appendix II-A (cont.)

	Name of Corporation	Principal Products	Location of Production Plants	Total 1979 Sales of Aerospace Products (Millions of U.S. $)
22.	Parker Hannifin	hydraulics,	California	
	(Bertea Corp.)	fuel systems,	Ohio	
		airsystems	New York	140.1
23.	Pneumo Corp.	landing gear,	Ohio	
	(Cleveland Pneumatic Tool)	miscellaneous	Michigan	
			Tennessee	
			Kansas	104.4
24.	Raytheon Co. Inc.	light aircraft	Kansas	
	(Beech Aircraft)	(Incl. airframe)		449.4
25.	Rockwell International	aircraft,	California	
	(North American Aviation)	(incl. airframe)	Texas	
	(Commander Aircraft)	rocket engines,	Ohio	
	(Rocketdyne)	miscellaneous	Oklahoma	
			Missouri	541.7

Appendix II-A (cont.)

	Name of Corporation	Principal Products	Location of Production Plants	Total 1979 Sales of Aerospace Products (Millions of U.S. $)
26.	Rohr Industries	jet engine nacelles	California	
			Washington	304.0
27.	Signal Companies Inc.	hydraulics,	California	
	(Airesearch)	air systems,	Arizona	
	(Garrett)	engine parts,	New Jersey	
		miscellaneous		862.0
28.	Sperry Rand Corp.	miscellaneous	Arizona	160.5
29.	Teledyne Inc.	hydraulics,	New York	
		electronics,	Missouri	
		engine parts,	Ohio	
		miscellaneous	Michigan	
			Alabama	214.6
30.	Textron Inc.	helicopters,	Texas	
	(Bell Hilicopter)	(incl. airframe)	California	
		hydraulics	New York	
			Louisiana	657.0

Appendix II-A (cont.)

	Name of Corporation	Principal Products	Location of Production Plants	Total 1979 Sales of Aerospace Products (Millions of U.S. $)
31.	Thiokol Corp.	rocket engines, rocket fuel, chemicals, explosives	Utah Alabama	138.0
32.	TRW Inc.	engine parts, miscellaneous	Pennsylvania California	118.5
33.	United Technologies (Pratt & Whitney Aircraft) (Sikorsky)	engines, engine parts, helicopters, (incl. airframe) miscellaneous	Connecticut California Florida West Virginia	3,173.8
		TOTAL 1979 SALES BY THESE 33 CORPORATIONS		24,726.4

Appendix II-B - The U.S. Aerospace Market by Product and Geographic Distribution for the year 1979 *

GEOGRAPHIC REGION	CATEGORY OF PRODUCT							
	Engines & Engine Parts		Aircraft Parts & Equipment		Aircraft		Total Aerospace	
	U.S. $ (Millions)	% of Total	U.S. $ (Millions)	% of Total	U.S. $ (Millions)	% of Total	U.S. $ (Millions)	% of Total
California	762	10.95	1,685	31.27	3,703	21.21	6,150	20.63
Western U.S. (excluding California)	898	12.90	603	11.19	3,020	17.30	4,521	15.17
Central U.S.	366	5.25	851	15.80	6,198	35.50	7,415	24.88
Eastern U.S.	4,937	70.90	2,248	41.73	4,538	25.99	11,723	39.33
TOTALS	6,963	100.00	5,387	99.99	17,459	100.00	29,809	100.01

* Source: Lockheed DIALOG Data Base through the American Society for Metals "Metadex information retrieval system.

APPENDIX II-C - MAJOR CANADIAN AEROSPACE MANUFACTURERS

	Name and Location	Products Made
1.	Bristol Aerospace Ltd., Winnipeg, Man.	engine parts, airframe parts
2.	Canadair Ltd., St. Laurent, Que.	aircraft, airframe parts
3.	De Havilland Aircraft of Canada, Ltd., Downsview, Ont.	aircraft, airframe parts
4.	Enheat Ltd., Aircraft Div., Amherst, N.S.	airframe parts
5.	Fleet Industries Div. of Ronyx Corp. Ltd., Fort Erie, Ont.	airframe parts
6.	Héroux Inc., Longueuil, Que.	landing gear, hydraulics, airframe parts
7.	McDonnell Douglas Canada Ltd., Mississauga, Ont.	airframe parts
8.	Menasco Canada Ltée., St. Laurent, Que.	landing gear, hydraulics
9.	Pratt & Whitney Aircraft du Canada Ltée., Longueuil, Que.	engines, engine parts
10.	Rolls-Royce (Canada) Ltd., Montreal, Que.	engines, engine parts

Appendix III-A - Organizations in B.C. Operating N.C. Machine Tools *

Note: N.C. Machine Tools which have been ordered, but were not installed as of August 1, 1980, are shown in brackets.

User and Location	Machine Type and Quantity	Products Made or Work Normally Performed
1. ACO Sales & Engineering Ltd., North Vancouver, B.C.	Gildemeister NEF lathe (1)	Forest Industry, and Mining Industry Products
2. Active Machine Works Ltd., Kelowna, B.C.	Boehringer VDF-PNE 480 lathe (1)	Mining, Forest Industry, and Transportation Products
3. Albion Industries Ltd., Kitimat, B.C.	Cadillac NC 100 lathe (1)	Mining and General Commercial Products
4. Bradson Machinery Ltd., Port Coquitlam, B.C.	Mori Seiki SL 1000 lathe (1) Takisawa TX 3 lathe (1)	Forest Industry, Petroleum, and General Commercial Products
5. B.C. Gearworks Ltd., Delta, B.C.	Hitachi Seiki lathe (1) Mori Seiki lathe (1) OKK MCV-500 Mach. Center (1)	Marine Products

* Sources: "Canadian Machinery and Metalworking" issues March 1978 and March 1980, plus various telephone and personal interviews.

Appendix III-A (cont.)

User and Location	Machine Type and Quantity	Products Made or Work Normally Performed
6. B.C. Institute of Technology, Burnaby, B.C.	Turr-E-Tape turret drill (1) Cadillac CNC Mach. Center (1)	Educational, no commercial work
7. Burke Machine Works Ltd., Vancouver, B.C.	Warner Swasey 2SC12 lathe (1) Warner Swasey 2SC15 lathe (1) Warner Swasey 3SC lathe (1) Sundstrand OM 1 Mach. Center (1) Cincinatti 10VC Mach. Center (1) (Warner Swasey 2SC15 lathe) (2)	Forest Industry, Petroleum, Mining and General Commercial Products
8. CAE Machinery Ltd., Vancouver, B.C.	Asquith Archdale NCR drill (1)	Forest Industry, Mining and General Commercial Products

Appendix III-A (cont.)

User and Location	Machine Type and Quantity	Products Made or Work Normally Performed
9. Canadian Aircraft Products Ltd., Richmond, B.C.	Bridgeport Series 1 CNC Mach. Center (1) Burgmaster VTC 325 Mach. Center (1) (Burgmaster VTC 330 Mach. Center) (1)	Aerospace Products
10. Canadian Car (Pacific) Div. of Hawker Siddeley Canada Ltd., Surrey, B.C.	Cincinatti Cinturn lathe (1) American Hustler 2010 lathe (1) Cincinatti 10HC-1500 Mach. Center (1) Avey DBM 32 Mach. Center (1) Pratt & Whitney Triax Mach. Center (2) Norte Verticent 2 Mach. Center (1)	Sawmill Machinery, Forest Industry, and General Commercial Products

Appendix III-A (cont.)

User and Location	Machine Type and Quantity	Products Made or Work Normally Performed
11. Canadian Underwater Vehicles Ltd., North Vancouver, B.C.	(OKK MCV-500 Mach. Center)(1)	Marine Products
12. Cominco Ltd.	Monarch VMC 75 Mach. Center (2)	Smelter and Mining Industry. Internal use only--no jobbing work.
13. CNC Machine Works Ltd., Enderby, B.C.	Mori Seiki SL 2 lathe (1)	Transportation and General Commercial Products
14. CNC Precision Machining, North Vancouver, B.C.	Excello No. 604 mill (2) Shizuoka AN5 Mach. Center (1) (Shizuoka AN5 Mach. Center)(1)	Aerospace and Electronics Products
15. Decade Industries Ltd. Richmond, B.C.	Excello Mach. Center (1) OKK MCV-500 Mach. Center (1) (OKK MCV-500 Mach. Center)(1)	Aerospace Products
16. Durand Machine Co. Ltd., New Westminster, B.C.	Warner Swasey SC 11 lathe (1)	Forest Industry and Marine Products

Appendix III-A (cont.)

User and Location	Machine Type and Quantity	Products Made or Work Normally Performed
17. Earl's Industries Ltd., Vancouver, B.C.	H.E.S. NCSA lathe (1)	Mining and Marine Products
18. Ebco Industries Ltd., Richmond, B.C.	Cincinatti CIM-X-Changer Mach. Center (1) Giddings and Lewis Planer (1)	Forest Industry, Mining, Aerospace and General Commercial Products
19. Ellett Copper & Brass Co. Ltd., Port Coquitlam, B.C.	N.C. drilling machines (2)	Forest, Petroleum, Chemical and Beverage Industry Products
20. Federal Pioneer Ltd. Richmond, B.C.	U.S. Amada Coma Turret Press (1)	Electronic Products--no jobbing work
21. Gearmatic Co. Ltd. Surrey, B.C.	Burgmaster Turret Drill (2) Burgmaster HTC 325 Mach. Center (1) Warner Swasey SC-15 lathe (1)	Proprietary lines of industrial and marine winches, and General Commercial Products

Appendix III-A (cont.)

User and Location	Machine Type and Quantity	Products Made or Work Normally Performed
Gearmatic Co. Ltd. (cont.)	Pratt & Whitney 12/60 lathe (2) Warner Swasey 2SC-15 lathe (1) Warner Swasey 3SC-24 lathe (1) (Cincinatti CIM-X-Changer Mach. Center) (1) (Warner Swasey 1SC-10 lathe) (1)	
22. Heede International Ltd., Port Moody, B.C.	Okuma LH-50-N lathe (1)	Cranes and General Commercial Products
23. Humble Manufacturing Co. Ltd., Vancouver, B.C.	W.A. Whitney Punchmaster 636 punch press	Electrical and Marine Products
24. ICAM Aerospace Corp. (B.C. Lower Mainland)	(Cincinatti Milacron 5-axis 3-spindle profiler gantries) (4)	Aerospace Products

Appendix III-A (cont.)

User and Location	Machine Type and Quantity	Products Made or Work Normally Performed
ICAM Aerospace Corp. (cont.)	(5-axis, 1 spindle profilers)(2)	
25. IMW Industries Ltd., Chilliwack, B.C.	Mazak M-5 lathe (1)	General Commercial Products
26. Kockums Industries Ltd. Surrey, B.C.	(Collet 3-axis horizontal bar mill)(1)	Sawmill Machinery, Forest, Mining and General Commercial Products
27. M & A Machine Shop Ltd., Port Coquitlam, B.C.	Mazak V-5 mill (1)	Specialized Commercial Products
28. Morfee Industries Ltd. Prince George, B.C.	Cadillac NC-100 lathe (1) Cadillac No. 2 mill (1)	Forest Industry Products
29. National Research Council of Canada, Vancouver, B.C.	Moog 83-1000 Mach. Center (1)	Research. No commercial work.

Appendix III-A (cont.)

User and Location	Machine Type and Qantity	Products Made or Work Normally Performed
30. N.C. Machining Ltd., Vancouver, B.C.	Cincinatti No. 3 Mach. Center (1)	Forest Industry Products
31. Newnes Machine Ltd. Salmon Arm, B.C.	Mori Seiki TL-58 lathe (1)	Forest Industry Products
32. Nicholson-Murdie Machines Ltd., Victoria, B.C.	American Hustler lathe (1) Cincinatti 10HC Mach. Center (1) Mazak M-5 lathe (1) (Cincinatti Cinturn lathe) (1)	Sawmill Machinery
33. Norvan Tools Ltd. North Vancouver, B.C.	Tree Journeyman (1)	Moulds for injection moulding
34. Prime Mover Controls Ltd., Burnaby, B.C.	Excello 602 mill (1) Hardinge HNS lathe (1)	Marine Products

Appendix III-A (cont.)

User and Location	Machine Type and Quantity	Products Made or Work Normally Performed
35. Q.M. Industries Ltd. Prince George, B.C.	Cincinatti 20HC mill (1) Cincinatti Cinturn lathe (1) Cincinatti 10V mill (1) Warner Swasey lathe (1)	Forest Industry, Petroleum and General Commercial Products
36. Regent Steel Specialties Ltd., Burnaby, B.C.	Wells 3-axis mill (1)	Sawmill Machinery—no jobbing work
37. Rovalve Ltd. Port Coquitlam, B.C.	OKK MCV-500 Mach. Center (1) Makino vertical mill (1)	Large valves for Forest Industry, Petroleum and Municipal Works
38. Singer Valve Surrey, B.C.	Monarch VMC-75 Mach. Center (1) OKK MCV-500 Mach. Center (1)	Agricultural and General Commercial Products

User and Location	Machine Type and Quantity	Products Made or Work Normally Performed
39. Stevested Machinery & Engineering Ltd., Surrey, B.C.	Warner Swasey SC-25 lathe (1) Toshiba MH-400 mill (1) (Toshiba MH-400 mill) (1)	General Commercial Products
40. Teleflex (Canada) Ltd., Vancouver, B.C.	Burgmaster Econo II Mach. Center (1)	Marine Products and Industrial Hydraulics
41. Tristar Industries Ltd., Richmond, B.C.	(Cincinatti M400 Mach. Center) (1)	Forest Industry, Petroleum, and Mining Products
42. Wagner Engineering Ltd. North Vancouver, B.C.	Cincinatti 10HC Mach. Center (1) Cincinatti CIM-X-Changer Mach. Center (1) Mazak Turret lathe (1) Moog 83-1000 Mach. Center (1)	Marine Products--no jobbing

Appendix III-A (cont.)

User and Location	Machine Type and Quantity	Products Made or Work Normally Performed
43. Weldco Ltd., Vancouver, B.C.	Cadillac 1000 lathe (1)	Industrial Hydraulics, Forest Industry Products
44. Wesdrill Equipment Ltd. Richmond, B.C.	Pratt & Whitney Tape-o-matic Mod. "C" mill (1) Mazak M-5 lathe (1)	Mining and Petroleum Industry Products
45. Westcan Engineering and Machine, Vancouver, B.C.	Eliot Niles DFS 400 lathe (1)	Forest Industry Products

Appendix III-B - N.C. Machining Facilities in B.C. with an Expressed Interest in Aerospace Machining Work (Based on Survey Information)

Note: Machines on order shown in brackets.

User and Location	Status re Aerospace Work	Machine Type	Programming	Control Type
1. Active Machine Works Ltd., Kelowna, B.C.	I	Boehringer VDF-PNE 480 lathe, 11" x 40"	2-axis contouring	Fanuc
2. Albion Industries Ltd., Kitimat, B.C.	I	Cadillac NC 100 lathe, 20" x 33"	2-axis contouring	Summit Bandit
3. Bradson Machinery Ltd.,	I	Mori Seiki SL 1000 lathe, 24" x 40" Takisawa TX3 lathe, 16" x 20"	2-axis contouring	Fanuc

Status re Aerospace Work

I Firms which have indicated interest in doing Aerospace machining work, but as of Aug. 1, 1980, had taken no definite steps with respect to quality control approval.

II Firms which have indicated interest in Aerospace and either have quality control system approval by at least one major aircraft manufacturer, or are in the process of obtaining such approval.

III Firms which are presently performing N.C. machining of aerospace parts, and are soliciting additional aerospace work.

Appendix III-B (cont.)

User and Location	Status re Aerospace Work	Machine Type	Programming	Control Type
4. Burke Machine Works Ltd., Vancouver, B.C.	II	Warner Swasey 2SC12 lathe, 20" x 30"	2-axis contouring	A-B 7360
		Warner Swasey 2SC15 lathe (3), 25" x 30"	2-axis contouring	A-B 7360
		Warner Swasey 3SC lathe, 40" x 30"	2-axis contouring	A-B 7360
		Sundstrand OM 1 Mach. Center, 36" x 36" x 36"	3-axis contouring	SWINC
		Cincinatti 10VC Mach. Center, 50" x 25" x 25"	3-axis contouring	Acramatic
		(Warner Swasey 2SC15 lathe (2)		
5. Canadian Aircraft Products Ltd., Richmond, B.C.	III	Bridgeport Series 1 CNC, 12" c 24" x 9"	3-axis contouring	Boss 6
		Burgmaster VTC 325, 40" x 20" x 12"	4-axis contouring	A-B
		(Burgmaster VTC 330)		

Appendix III-B (cont.)

User and Location	Status re Aerospace Work	Machine Type	Programming	Control Type
6. Canadian Car (Pacific) Division of Hawker Siddeley Canada, Ltd., Surrey, B.C.	*	Cincinatti Cinturn lathe, 18" x 18"	2-axis contouring	Cincinatti TC
		American Hustler 2010 x 102 lathe, 10" x 102"	2-axis contouring	GE 7542
		Cincinatti 10HC-1500 Mach. Center, 60" x 40" x 26"	3-axis contouring	Cincinatti M
		Avey DBM 32 Mach. Centre 36" x 60" x 16"	3-axis pt. to pt.	GE 7500
		Pratt & Whitney Triax 26 x 40 Mach. Center, 26" x 40" x 27"	3-axis contouring	Pratt & Whitney
		Pratt & Whitney Triax 26 x 54 Mach. Center, 26" x 54" x 27"	3-axis contouring	Pratt & Whitney
		Norte Verticent 2 Mach. Center, 22" x 39" 27½"	3-axis contouring	Fanuc F5M

* Canadian Car advise that they are presently making some aircraft parts by N.C. machining. However, they advise that their N.C. machining capacity which is available for outside work is not committed to any particular market.

Appendix III-B (cont.)

User and Location	Status re Aerospace Work	Machine Type	Programming	Control Type
7. CNC Machine Works Ltd.,	II	Mori Seiki SL2 lathe, 16" x 18"	2-axis contouring	Fanuc
8. CNC Precision Machining, North Vancouver, B.C.	III	Excello No. 604 mill (2) 28" x 14" x 11"	3-axis contouring	Summit Bandit
		Shizuoka AN5, 28" x 14" x 20"	3-axis contouring	Summit Bandit
		(Shizuoka AN5)		
9. Decade Industries Ltd., Richmond, B.C.	III	Excello Mach. Center, 34" x 12" x 6"	3-axis contouring	Summit Bandit
		OKK MCV-500, 40" x 20" x 20"	3-axis contouring	Mitsubishi
10. Ebco Industries Ltd., Richmond, B.C.	III	Cincinatti CIM-X No. 3, 30" x 34" x 47"	2-axis contouring	Acramatic
		Giddings & Lewis Planer	3-axis profiling	Gen. Num. No. 7
		Mills (2), 192" x 48" x 56" and 180" x 60" x 104"		

Appendix III-B (cont.)

User and Location	Status re Aerospace Work	Machine Type	Programming	Control Type
11. ICAM Aerospace Corp.,	**	(Cincinatti Milacron 5-axis, 3-spindle profiler gantries)(4) (5-axis, 1-spindle profiler)(2)		
12. IMW Industries Ltd., Chilliwack, B.C.	I	Mazak M-5 lathe, 24" x 80"	2-axis contouring	Fanuc
13. M & A Machine Shop, Port Coquitlam, B.C.	II	Mazak V-5 mill, 30" x 16" x 25"	3-axis contouring	Fanuc
14. Morfee Industries Ltd., Prince George, B.C.	I	Cadillac NC 100 lathe, 22" x 48"	2-axis contouring	Summit Bandit
		Cadillac No. 2 Mill, 5" x 15" x 32"	3-axis contouring	Summit Bandit

** As of August 1, 1980, ICAM Aerospace Corp. did not have an operating plant facility.

Appendix III-B (cont.)

User and Location	Status re Aerospace Work	Machine Type	Programming	Control Type
15. Newnes Machine Ltd., Salmon Arm, B.C.	I	Mori Seiki TL-5B lathe, 24" x 40"	2-axis contouring	Fanuc
16. Nicholson-Murdie Machines Ltd., Victoria, B.C.	I	American Hustler 2020 x 120 lathe, 21" x 102"	2-axis contouring	GE 7442
		Cincinatti 10HC Mach. Center, 100" x 40" x 40"	3-axis contouring	Cincinatti
		Mazak M-5 lathe, 24" x 60"	2-axis contouring	Fanuc
		(Cincinatti Cinturn lathe)		
17. Prime Mover Controls Ltd., Burnaby, B.C.	I	Excello 602 Mill, 24" x 12" x 6"	3-axis contouring	GE
		Hardinge HNS bar & chuck lathe, 9" x 12½"	2-axis contouring	GE
18. QM Industries Ltd., Prince George, B.C.	II	Cincinatti 20 HC mill, 100" x 36" x 28"	3-axis contouring	Cincinatti

Appendix III-B (cont.)

User and Location	Status re Aerospace Work	Machine Type	Programming	Control Type
QM Industries Ltd. (cont.)		Cincinatti Cinturn lathe, 17½" x 100"	2-axis contouring	Cincinatti
		Cincinatti 10V mill, 50" x 26" x 20"	2-axis contouring	Cincinatti
		Warner Swasey Chucker lathe, 14½" x 20"	2-axis contouring	Allen-Bradley
19. Stevested Machinery & Engineering Ltd., Surrey, B.C.	II	Warner Swasey SC25 lathe, 25" x 47"	2-axis contouring	Warner Swasey
		Toshiba MH 400 mill, 36" x 16" x 18"	3-axis pt. to pt.	Millcron
		(Toshiba MH 400 mill)		
20. Teleflex (Canada) Ltd., Vancouver, B.C.	II	Burgmaster Econo II Mach. Center, 20" x 40"	2-axis pt. to pt.	Westinghouse
21. Weldco Ltd.	II	Cadillac 1000 lathe, 12" x 33"	2-axis contouring	Fanuc

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