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FURTHER CASES ON THE MANAGEMENT OF
TECHNOLOGICAL INNOVATION AND
ENTREPRENEURSHIP

by

M.J.C. Martin and P.J. Rosson

Dalhousie University
June 1986

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The views and opinions expressed in this report are those of the authors and are not necessarily endorsed by the Department of Regional Industrial Expansion.

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INTRODUCTION

In an earlier report (1), the authors argued the need for the preparation of teaching case studies on the management of technological innovation and entrepreneurship in a Canadian setting. It provided four such studies based upon four small to medium sized Nova Scotian companies. This report constitutes a sequel by providing six further studies based upon five medium to large companies with operations elsewhere in Canada and abroad.

As with the earlier cases, the firms here have experienced mixed fortunes in their pursuit of technological innovations and corporate growths. Three of them could be described as still young, since they were founded in the early 1970s. Connaught Laboratories, with origins going back to 1914, did not become independent of the University of Toronto until 1970, and then faced the challenge of corporate role definition in the biologicals and pharmaceuticals industries. Gandalf and Mitel, two of the success stories of the 1970s in Silicon Valley North, faced the challenges of following success with success in the rapidly changing telecommunications marketplace. The two remaining firms involved are mature. Although not founded until after World War II, CAE (Electronics) of Montreal has established an enviable international reputation in the flight simulators and related businesses, whilst Imperial Oil is the Canadian affiliate of Exxon Corporation.

Teaching Notes for these six cases (together with their four predecessors), as well suggestions for the incorporation in appropriate courses, are discussed in a Supplement to this Main Report. Complimentary copies of this Supplement are available on a restricted basis to technology managers and bona fide teachers from the following:

Ms. Louise Williamson,
Department of Regional Industrial Expansion,
Office of Industrial Innovation (EOII),
235 Queen's Street,
Ottawa, Ontario
Canada, K1A 0H5

The authors welcome criticisms, comments, questions or suggestions concerning both the cases and the teaching notes. We should also like to thank the flatteringly large number who wrote to express their appreciations of our earlier efforts. We do hope that you will also find these of interest.

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REFERENCE

1. Martin, Michael J.C. & Rosson, Philip J. Four Cases on the Management of Technological Innovation and Entrepreneurship, Department of Regional Industrial Expansion, Ottawa, 1982.

CONNAUGHT LABORATORIES LTD. - THE VICOGEN PROJECT - Search for a "Cash Cow"

Corporate History

Connaught's origins go back to the year of the outbreak of World War I. In the previous year (1913), Dr. J.G. Fitzgerald, Associate Professor of Hygiene at the University of Toronto visited Europe's leading medical research establishments. He was especially impressed with the Pasteur Institute in Paris and Lister Institute in London, so returned to Canada resolved to create a similar facility in his own country. On May 1, 1914 the Board of Governors of his University approved the establishment of "The Antitoxin Laboratory in the Department of Hygiene" with a mission to produce diphtheria antitoxin and other public health serums and vaccines for distribution and sales throughout Canada. Dr. Fitzgerald became its first Director - a post he was to hold for over 30 years until his retirement in 1955.

Three months after its creation, World War I began and the new Laboratory was immediately enlisted into the national war effort by providing tetanus antitoxin as well as smallpox and typhoid vaccines to the Canadian Armed Forces. Later other products were provided to ameliorate the horrors of war and pestilence, including the emergency production of antimeningococcus serum and influenza vaccine to treat widespread fatal outbreaks of meningitis and influenza among Canadian troops. By the end of that war the new Laboratories had earned national recognition and their name was changed to "Connaught

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This case was prepared by Professors Michael Martin and Philip Rosson of Dalhousie University as a basis for class discussion rather than to illustrate effective or ineffective handling of an administrative situation. Some of the data and information have been changed to preserve commercial confidentiality. The authors gratefully acknowledge the financial support of the Federal Department of Regional Industrial Expansion, Office of Industrial Innovation in the development of this case.

Antitoxin Laboratories" in honour of the Duke of Connaught the then Governor-General of Canada. In 1920 the Laboratories were granted an independent status within the University of Toronto, whilst still sharing a common Director (Dr. Fitzgerald), laboratory space and senior staff with the School of Hygiene.

Connaught's first decade was chiefly associated with its role in the development of insulin. In 1922, (later Sir) Frederick Banting and Charles Best of the University's Medical School clinically demonstrated the efficacy of insulin in controlling the blood sugar level of diabetic patients at the Toronto General Hospital. This discovery meant that countless lives of diabetics could (and still are) saved by regular daily insulin treatment. To achieve this goal, it also meant that methods for the mass-production of insulin had to be developed - itself an awesome task. Dr. Fitzgerald offered the Connaught's facilities for the performance of this pioneering life-saving work, which began in that same year under Charles Best's guidance. Later other laboratories co-operated in the work (including those of Eli Lilly in the US), but Connaught remained the sole supplier of Canadian insulin needs for many years. The insulin patents were retained by the University and administered as a trust for the public benefit.

Given the broadening mission of the laboratories the term "Antitoxin" was deleted from their title in 1923, and the insulin work was not the sole example of Connaught's pioneering public spirit. In 1924, Dr. Fitzgerald again visited the Pasteur Institute and was impressed with Dr. Ramon's work on diphtheria toxoid. He immediately cabled his Laboratories with instructions for toxoid preparation and the first samples were produced within a few months. Successful clinical trials followed and, by 1930, Canada became the second nation (after France) to provide an active immunization programme against diphtheria for all its children.

Connaught continued its expansion throughout the 1920's and 1930's developing numerous new products and processes. A Western Division was opened in 1935 in the Province of British Columbia. As in 1914, the outbreak of World War II in 1939 led to further expansion to meet the needs of the Armed Services. A Veterinary Section was established to research, develop and manufacture veterinary biologicals (see later). Typhus vaccines were mass-produced for the first time, together with combined vaccines for diphtheria and pertussis (whooping cough), typhoid-paratyphoid-tetanus as well as blood serum. The work on combined vaccines continued throughout the 1940's, so that Canada and Connaught provided world leadership in this field. In 1943, Connaught began making penicillin and was a major developer of improved crystallization methods for producing the life-saving antibiotic.

After World War II, from 1948 onwards the Laboratories became active participants in tissue culture research playing a forefront role in this important new field. This expertise led to their participation in process research and production of both the Salk and Sabine poliomyelitis vaccines in the 1950's and 1960's. Although this work was a dominant concern for these two decades, research and production on new and improved products and processes continued in other areas.

In 1955 Dr. Fitzgerald retired and it was decided formally to separate Connaught Laboratories and the School of Hygiene, whilst still retaining their overall mission and the policy of cross-appointments. By this time, the Laboratories' annual research budget had risen to $600,000 (two-thirds generated from internal funds and the balance from external grants).

As already indicated, the new Director led Connaught Laboratories to a further seventeen years of sustained growth based upon many substantial innovative contributions to human and animal care. However, by the time of his own retirement in 1972, it was recognized that Connaught's historically successful role could no longer be sustained for several reasons.

First, its branch of the industry - vaccines and other biologicals - was largely concerned with preventive health care products developed in response to requirements from national and international agencies. National organizations tended to favour their own domestic producers, and both national and international agencies were primarily interested in buying products at the lowest prices available world-wide. Such a requirement suited the strategies of Eastern Bloc producers who were anxious to build-up sales in Third World nations and would accept low returns to gain market entry into such countries. Second, as well as tough price competition, Connaught experienced another problem. Production of organically-based health care biologicals demands costly high-technology facilities and long lead-times. For example, Connaught took 18-24 months to produce and test insulin in the early 1970's. In contrast, chemically-based pharmaceutical products were typically more profitable and some large US companies - e.g. Dow Chemical, Eli Lilly and Merck, Sharp and Dohme - had dropped some biologicals to concentrate on more lucrative pharmaceutical products. Third, by 1972 Connaught employed some 800 people and despite repeated physical expansions its facilities were in need of an overhaul. A number of senior staff were approaching retirement and its recruitment policies had not entirely kept pace with technological changes. Morale moreover was lower than in the past and, given its current size and complexity, a university as an institution was really unsuited to the task and financial investment that the dictates of organizational renewal required.

In 1970 the Canadian Development Corporation (CDC) was founded as a crown corporation with a mission to increase national ownership in key technology-based industries. The biologicals industry was perceived as a prime sector for investment, so Connaught became its first purchase in the summer of 1971 for $24 million from the University of Toronto.

The Veterinary or Animal Health Division

Connaught's animal health activities, particularly in the context of their use as experimental or host subjects, can be traced back to its earliest days, but a formal Veterinary Section was not established until 1940 as part of the Laboratories "war efforts". At the outbreak of World War II there was a fear that animal diseases, either naturally occurring or artificially induced by enemy action, might cripple the war economy. This fear generated research on preventive animal health measures. The Laboratories also developed a tri-valent antitoxin for treating gas gangrene and its mass-production required a stable of 1,000 horses. Mercifully, these contingency efforts were not required in practice, since none of the belligerents resorted to either biological or poison gas warfare, but they did increase the Laboratories' expertise in veterinary health.

This expertise grew in the two decades following that war and, by the 1950's, annual sales of animal health products had reached $1-2 million. All its products were marketed through distributors. Early post-war work led to the development of poultry and rabies vaccines. Canadian and US licenses were awarded for several poultry vaccines in 1956 and nine years later for the ERA rabies vaccine. This vaccine rapidly enjoyed world-wide use on livestock and domestic pets in countries where rabies was enzootic. Later another rabies vaccine was developed for human use. The animal health work also led to the development of vaccines for dogs against distemper and hepatitis and for other small animals such as cats and mink. For much of this time the Division was directed by Dr. John Crawley - a very good researcher who initiated many creative ideas. One of his then colleagues describes him as: "A fellow who had ideas like a machine-gun spitting bullets. After talking to him for ten minutes you couldn't wait to get back to your lab. to start researching his ideas".

By the late 1960's, under Dr. Crawley's leadership, the Division was a solid contributor to Connaught's overall efforts, and started to develop a vaccine against atropic rhinitis (inflammation of the nasal mucous membrane) in pigs. This disease puts the pigs off their feed, extending the time it takes for them to reach market weight, with a consequent major negative impact on the economics of the "pork manufacturing" operation. The development of the vaccine against this and other swine diseases required research on disease-free pigs and this presented a difficult problem. Given that the disease was endemic to pigs, it was impossible to secure the supply of disease-free experimental animals required. For this project to continue it was therefore necessary to establish a disease-free pig herd. Such a herd was built up at a 200 acre farm which had been purchased at Bolton near Toronto for the expansion of animal colonies. Although the original purpose of this herd was to provide disease-free experimental animals, it was quickly recognized that disease-free pigs could be brought to market weight some 10-15 days quicker than the typical beast. This meant that pork could be produced from disease-free pigs at a lower cost, so it was decided to enter the disease-free pig breeding business. The Bolton Farm was expanded to 600 acres coupled with an investment of about $1.5 million in physical plant. The herd was expanded to 3,500 swine.

Unfortunately, this venture ran into difficulties. First, the price of pig feed skyrocketed so it was decided that the Division should grow its own feed. This required the construction of large silos to store that feed. Second, problems were experienced with the housing feeding and nutrition of the herd. Also, by this time seed herds had been established in various parts of Canada, so similar problems were experienced in servicing these herds throughout the country. Third, despite the most careful precautions, some infection did appear in these seed herds. By the latter half of the 1960's, Dr. Crawley found himself totally enmeshed in these problems and was forced to delegate research on production of veterinary products to subordinates. The capital and operating costs of the Division had also soared, so that it was no longer a profitable operation.

This was the situation which the new president, Donald McAskill faced when he took charge of Connaught following the CDC purchase in 1972. He took prompt remedial action. The pig farm at Bolton was closed down and the herd disbanded. He also saw that Dr. Crawley's research talents were being dissipated in a purely managerial role, so he appointed Archie Ferguson as General Manager of the Division. Mr. Ferguson had been secretary of Connaught during its university affiliation and had a strong business and financial background. Dr. Crawley was offered the position of Research Director where his talents could focus on new product developments. Much to the regret of everyone at Connaught, he declined the offer to enter full-time farming in the Guelph area in Southern Ontario.

Mr. Ferguson introduced effective cost and managerial controls to improve the financial performance of the Division and then initiated negotiations for joint ventures with outside companies to bring in new technology. However, it was also recognized that a more market-oriented approach was required, including the establishment of a direct sales force for veterinary products.

With this end in view, an experienced marketeer, Mr. Douglas Sansom was hired from Pitman Moore (another manufacturer and distributor of veterinary products)to build-up a marketing arm involving the hiring and training of a direct sales force to replace the distributors. When the time came for Mr. Ferguson to return to corporate responsibilities in 1977, Mr. Sansom took charge of the Division. He was joined by Dr. Mike Walcroft as his deputy who could provide the research and production skills to complement his own marketing and business expertise.

Dr. Walcroft was hired by Connaught in 1958 specifically to look after the monkey colony. He had just graduated with a doctorate in veterinary medicine from the University of Guelph. Monkeys had been and were being used extensively as experimental and host animals, particularly in the production of Salk poliomyelitis vaccine. At the time of his appointment the colony consisted of some 3,000 monkeys. It was important that these animals should be supervised by a qualified veterinarian both to satisfy research and production needs and to protect the staff handling them. Serious and sometimes fatal diseases can be readily transmitted from monkeys to man, so stringent safety precautions must be maintained in such colonies.

In the following years Dr. Walcroft assumed increasing responsibilities in animal care, production and operations. In the mid-1960's it was decided to consolidate animal care on a company-wide basis and an Animal Resources Division was created, with Dr. Walcroft as Director, and an annual budget of approaching $1 million (about 10% of the total Connaught budget at the time). Later, in the early 1970's, the Division was made part of a larger Operations Services Division responsible for company-wide production planning. inventory control, packaging and filling and physical plant. Dr. Walcroft subsequently took charge of this enlarged division, where he remained until a further corporate re-organization in 1977. This re-organization was initiated by the newly appointed President, Mr. Alun Davies. As well as accepting the need for a market-oriented mission for the Veterinary Division, he believed that the various operations services should report functionally (purchasing to finance etc.) so the Operations Services Division was disbanded. This released Dr. Walcroft to join Mr. Sansom in leading the efforts to rehabilitate the Veterinary Division.

The Vicogen Project

When Dr. Walcroft moved to the Veterinary Division with responsibility for research, production and quality control he immediately recognized the difficulties he faced. Research staff and facilities had been radically cut back as part of the recent cost containment efforts which, coupled with Dr. Crawley's declining involvement and then departure, meant that R&D had sadly declined in both quantity and quality. There were now only four research scientists in the Division (plus some technical support staff) who had to cope with 32 different research projects. In consequence efforts were so diluted that nothing was completed.

Production facilities were also outdated. When they were built, veterinary vaccines were grown in eggs, but by the 1970's they were grown in tissue cultures. Products were also still being grown in large square cross-section medicine bottles which, by then had been replaced by continuously rotating circular cross-section "roller bottles" elsewhere which gave a much higher yield. This follows because cells attached to the surface of the vessel grow and divide where the inner surface of the vessel contacts with the fluid and replicate only where there is contact with the nutrient medium. In stationary cultures this is essentially restricted to one surface, whereas in roller cultures (or vessels) the entire surface of the container is bathed in nutrient medium. Production flow patterns were also outdated, inefficient and no longer fully complied with Canadian and US regulatory requirements.

The Division's products were also outmoded in the market-place. Vaccines are typically injected into an animal by a veterinarian or farmer. Connaught's products required 2 ml. dosages which could only be injected intramuscularly. By this time, the competitive products available required only a 1 ml. dosage which could be injected either intramuscularly or subcutaneously. These latter products were therefore cheaper and easier to inject. The disadvantages of the aging product line and production facilities were, of course, compounded by the fact that the Division - until Mr. Sansom was appointed - had had no direct sales force but marketed all its products through distributors.

Dr. Walcroft recognized that it would be impossible to develop new products and improve existing production facilities with the limited resources available and that, in the immediate future, it might be better to acquire good technology from elsewhere. He therefore began to read the technical literature for sources of new product ideas and came across the work of the Veterinary Infectious Diseases Organization (VIDO) of the University of Saskatchewan in Saskatoon. What struck him was the similarities in roles between VIDO in 1977 and Connaught in 1914. That is, both were set up under university umbrellas as vaccine research institutions with no immediate manufacturing mandates. Given their common genesis, Connaught's Veterinary Division might well be an attractive manufacturing partner for VIDO.

Doug Sansom and Mike Walcroft flew off to Saskatoon to explore this promising possibility and received a positive response. Confidentiality agreements were quickly exchanged between the two organizations and the two men reviewed the VIDO research projects. What jumped right out at them was the vaccine which had been developed to treat diarrhoea in cattle. This disease kills recently born calves and had been a major problem in the cattle industry for many years.

Such calves can develop and often die from diarrhoea caused by three different infectious agents: (i) E. coli, (ii) Rota virus and (iii) Infecturate Corona virus.

E. coli scours typically develops within the first five days of the calf's life, whilst the other two occur later. At that time there was no vaccine for E. coli scours and the vaccines for treating the other two viruses, marketed by other veterinary products manufacturers, were not totally effective. Given the size of the North American cattle industry, new more effective treatments for these diseases offered considerable commercial promise. VIDO was performing work on new or improved vaccines for all three and the greatest progress had been made on the vaccine for E. coli scours. Preliminary results with this vaccine indicated that injecting it into the cow prior to the calf's birth passively immunized the latter against that disease. This meant that Connaught had two alternative options which could pursue:

a) Enter into a licensing agreement with VIDO to develop, manufacture and market the K99 E coli vaccine (K99 was the numerical designation of the protective antigen) as a mono-component. Given K99's advanced state of development, this could probably be done quite quickly. In say one or two years.

b) Enter into a licensing agreement with VIDO to develop and market all three vaccines, then package and market them as a triple-vaccine which would protect calves from all three diarrhoeas. This would be a much more attractive product than the single E. coli scour vaccine alone and Connaught could realistically expect to be the first company to market such a triple-vaccine. Unfortunately it suffered from three disadvantages. First, since development work on K99 was more advanced than on the other two, VIDO would need to complete more R&D on the rota and corona vaccines before the "know-how" was ready for transfer to Connaught. Second, Connaught would have to acquire that "know-how", perform the further development required and then upgrade the process to full-scale production on three vaccines instead of one. This would undoubtedly take significantly longer than on K99 alone as well as impose an added burden on Connaught's limited resources. It would delay the market launch and therefore the positive cash-flow infusion sought from the final product. Third, although K99 was a novel vaccine, it was possible that the other two violated existing US patents. Connaught's lawyers advised them that although any legal suit against the company for patent infringements was unlikely and would probably be thrown-out of the US courts, this favourable outcome could not be guaranteed. Moreover, such action could possibly sour US-Canadian relations, given Connaught's status as a Canadian crown corporation by virtue of its CDC ownership.

Doug Sansom, Mike Walcroft and others mulled over these two alternatives for some time. In the end, they decided upon the first option, so VIDO and Connaught signed a licensing agreement whereby Connaught would produce and sell the K99 vaccine to be known as Vicogen. Connaught paid VIDO a fixed fee and agreed to a royalty rate on future sales of the product. Mike Walcroft was named leader of the Vicogen Project with responsibilities for the transfer of the technology to Connaught, creating the production facilities there, arranging the licensing clearances with the regulatory authorities and distributing the product to the marketplace. Doug Sansom was responsible for the overall marketing aspects - market analysis research and strategy.

Under Dr. Walcroft's direction, Vicogen was produced and received governmental approval in 11 months. He attributed this remarkably short time to several factors. First, total support from Alun Davies and the rest of Connaught's senior management. All saw Vicogen as a top priority project which would revitalise the fortunes of the Division. It was expected to provide steady annual sales of about $15 million over some years and the profit from these sales would be used to up-date the Division's product line and modernize its physical plant. Second, VIDO had performed excellent research in developing the vaccine, so the problems of scaling-up production to commercial quantities were minimized. Third, this scaling-up process in the biologicals industry requires the participation of a team of typically about half-a-dozen members with varied disciplinary and management backgrounds, and Dr. Walcroft was able to co-opt a particularly strong and well-balanced team from Connaught's staff. Fourth, well-suited development space was readily available at that time (see next paragraph).

One of the first persons Dr. Walcroft co-opted to join the team was Dr. Dennis Stainer, Director of the Bacterial Vaccines Department at Connaught. The VIDO work had demonstrated the unquestionable efficacy of the vaccine, but their laboratory scale operations were unable to offer commercial level outputs so major changes in production methodology were required. Dr. Stainer was very experienced at growing new bacterial vaccines and furthermore, at that time, was introducing fermenter technology into Connaught. Fermenters are large tanks, around 500 litres in volume, in which bacteria are grown. By applying this technology it would be possible to mass produce the vaccine at a very low cost indeed eing a good resarcher, Dr.

Stainer was excited by the challenge involved and became another avid supporter of the project. Moreover he mobilized the support of his Department behind it. The early developmental research was performed in a vacant building which was fully air-conditioned and had already received approval for such work by the regulatory authorities. (These authorities require that "development" and "production" should be performed in separate facilities.) Later, as development research was completed, the work was transferred to large fermenters built in the Bacterial Vaccines Department. Approval for this facility had to be obtained from both the human and animal vaccine authorities in Canada and the US.

The developmental research was performed in close collaboration with VIDO, especially Dr. Steve Ackers, VIDO's first-class principal scientist who had pioneered the vaccine. Many trips and even more telephone calls were made between Connaught and VIDO. An open relationship was built up very quickly between the researchers from the two organizations. Soon the two groups were "socializing hard" as well as "working hard" together! The procedures and protocols used by Dr. Ackers to grow the organism were carefully identified and duplicated in the Connaught developmental research facility. Samples of the cultures grown were then sent to VIDO to be assayed. This was necessary because two identical assay procedures in different laboratories will produce different results from the same sample. Therefore Connaught's cultures of the K99 antigen had to be assayed at VIDO until they exactly replicated the cultures grown there. Once this replication had been achieved at Connaught, the culture growth regime or parameters could be altered (eg. increasing oxygen or glucose, adjusting pH value etc.) to alter the growth rate. Much time was spent at Connaught experimenting with various combinations of parameters to identify the combination which provided the maximum growth rate of the culture.

The various tasks were undertaken by individual specialists in the project team. Much of the developmental research to determine the optimal growth characteristics of the culture was performed by Dr. Helen Blake (a biochemist) with Dr. Gupta (a microbiologist) and Ms. Karen White (a technologist) who focused on the assaying studies. Egon Kellner, who was Dr. Stainer's chief of production, worked with the latter, both at VIDO and Connaught, to learn VIDO's technology and then upgrade it from laboratory through development to full-scale production. Throughout the process other team members handled the regulatory requirements. Dr. Margaret Maxwell followed on the assaying work to design the quality control and other testing procedures on the product throughout the production process. Dr. Boylan (a veterinarian) was responsible for the clinical trials. He designed and recorded the results of field studies in which cows were injected with the vaccine and infected with the disease to challenge the vaccine's efficacy and toxicity. Drs. Boylan and Maxwell jointly presented their results to the regulatory authority (Agriculture Canada) in Ottawa. They established a very good rapport with their opposite numbers in Ottawa who ensured that the project received priority treatment there, so that bureaucratic delays were minimized. The US licensing procedure was initiated some three months after it began in Canada and was again completed in record time, thanks to the co-operation of friends and colleagues in Connaught's US subsidiary in Swiftwater, Pennsylvania. The last, but by no means the least important member of the team was Dr. Ken Lawson, Director of Veterinary Research for Connaught. Although his management responsibilities precluded day-to-day participation he was frequently asked for advice and his vast experience enabled him to make valuable contributions and comments on many aspects of the team's work.

As project leader, Dr. Walcroft called frequent team meetings to compare notes, thrash out problems and ensure that all the tasks were adhering to the project time-table. Thrice weekly meetings were held during the crucial phases of the project - usually on Monday, Wednesday and Friday afternoons. Dr. Walcroft minimized the paperwork required and short-circuited the internal bureaucracy. In this he was very ably assisted by Ms. Helen Blade whom he described as a "real fireball". She was expert at getting things done and sorting out the paperwork afterwards. The overall project was completed within a year. Vicogen proved to be a very stable product which was easy to produce with a high yield and potency. From a research and production viewpoint, it was an outstanding success.

When the Agriculture Canada licence was issued on 14 December 1979, the Vicogen team breathed a collective sigh of relief. Timing was crucial for marketing the product to farmers, spring calving requiring the immunization of herds at Christmas. In anticipation of approval for Vicogen, Connaught had speculatively built up inventory levels and lined up trucking firms so that they could get the product onto the farm at the appropriate time.

As already stated, Doug Sansom took charge of the marketing aspects, assisted by Dave Greig who was marketing manager for veterinary products. Concurrently with the development of Vicogen, a detailed market analysis (which mainly focused on the U.S.), was performed by a market research company in New York City, who produced a very impressive report. They estimated that there were 10 million cows in the US and 95% would calve, to give a potential annual market of 9.5 million doses. The Vicogen share of this market was estimated at 3.9 million doses which would yield an annual revenue of $6.5 million.

The decision to move from distributors to a direct sales force was implemented with the project, so 32 (26 in the US and 6 in Canada) salesmen were quickly hired and trained. They formed a capable group who were very knowledgeable about the product. The vaccine was sold to veterinarians rather than farmers following the normal practice in that industry. Promotion to support the direct sales efforts was directed at both farmers and veterinarians. It took the form of advertising on local radio, in farming magazines and veterinary medicine journals. Veterinarians also received promotional material by direct mail.

Despite these efforts, sales of Vicogen proved to be disappointing amounting to no more than one-third of the above estimate. In the opinions of experienced individuals such as Drs. Boylan, Lawson and Walcroft, Vicogen did extremely well for a veterinary product and contributions were sufficient to cover the project's costs within one year of market launch. Unfortunately, it failed to yield the high sustained contribution needed to subsidize the Veterinary Division's resurgence whilst further new products were developed. Top management were therefore forced to review the Division's continued existence.

The Division's Demise

These reviewers concluded that the Division's continued operation was no longer congruent with corporate strategy. This decision was taken very reluctantly because many, including Dr. Bill Cochrane (Connaught's Chairman and CEO), believed that animal vaccines should be part of Connaught's product portfolio in the long- term. He suggested a number of alternatives to maintain the Division's existence but, regrettably, was forced to recognize that short-term commercial prudence dictated that its separate operations should be phased-out.

Divisional personnel, including Doug Sansom and Mike Walcroft, were transferred to other duties, the last to become Technical Projects Director. Veterinary quality control (QC) was absorbed into the corporate QC department and all veterinary vaccine production (including Vicogen) was transferred to the human viral vaccines production function. The direct sales force was disbanded and sales were again made through distributors. The phase-out was completed more rapidly than expected because, once it was known that Connaught intended to close-down the Division, many of its customers switched to competitive products. Nevertheless, Vicogen is still being sold and many hope that the Veterinary Division will enjoy a Phoenix-like re-birth at some later date based upon Connaught's current R&D efforts.

GANDALF

> "Alexander Graham Bell didn't realize it, of course, but what he invented in 1876 was the first computer terminal. Until late, the phone's role in the computer world has largely been auxiliary: computers have used the phone for the same reason people use it -- to talk to one another."
>
> David E. Sanger, New York Times.

Start-up

Gandalf was founded in 1970 by two under-employed entrepreneurs, Desmond Cunningham and Colin Patterson, who were short on capital but long on experience. By 1985 it had grown into a multinational corporation with annual sales of $85M and manufacturing operations in Canada, the U.S. and U.K.

Des Cunningham was born in 1931 and raised in Yorkshire, England -- a cradle of the first industrial revolution. He still retains the bluff down-to-earth personality of the typical Yorkshireman. He trained as an accountant but rapidly moved into sales and marketing. At one time he sold bread around the streets of London. He entered the computer business in 1959 by joining Elliot Automation of London, England where he worked for eight years ending as export sales manager with responsibility for selling Elliot computers throughout the world. In 1967 he moved to Canada, where he worked for Control Data Corporation

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(CDC) of Canada as a salesman of computer systems. It was there that he met Colin Patterson.

Colin Patterson was born in London, England and obtained a degree in physics from London University. He worked for five years in the British aerospace industry gaining invaluable experience by participating in the development of one of the world's first transistorized airborne digital navigational computers. He moved to Canada in 1965, first working for Computing Devices of Canada before joining CDC.

It has been said that little boys dream and wise men scheme, and after working at CDC, Cunningham and Patterson dreamt of forming their own company. In 1970 they turned their dreams into schemes and founded Gandalf Data Communications Ltd. (GDCL) as a joint partnership. Since their children were fascinated by 'The Lord of the Rings' saga they adopted the name of Tolkien's wizard for their company and a fictional character became a corporate reality.

They reputably began by selling design services and other consulting work from the lobby of Ottawa's Skyline Hotel, using a pay-phone to communicate with potential clients, but shortly afterwards moved into a 400 sq. ft. facility in the city. Patterson provided the technical expertise required by clients, whilst Cunningham supplemented reserves by selling equipment imported from the U.S. Their ultimate objective, however, was to manufacture their own products.

They quickly seized an opportunity to do so through their contacts in the computer centre of the federal government's Communication Research Centre (CRC) in Ottawa. The CRC required a short distance modem (MOdulator/DEModulator) unit, that is, a device which would transmit data along a telephone line at higher than normal speeds in the asynchronous mode over comparatively short distances. Only long distance modems were then commercially available. Gandalf designed and built the first prototype. It met the required performance specifications so, within three months, the CRC purchased some 30 units. Thus in its first year Gandalf designed, manufactured and sold its first product -- the asynchronous local data set (which they called the LDS 100), which could transmit data up to 13 miles at a price tag equal to four month's rental of conventional telephone company modem. designed to transmit data over long as well as short distances. Given these competitive characteristics, the company quickly sold more units. By 1971, Bell Northern Research (BNR), the Royal Canadian Mounted Police (RCMP) and Atomic Energy of Canada (AEC) had joined an expanding list of customers for Gandalf's product in Ottawa, Montreal and later Toronto. This success led to the name 'Gandalf box' being adopted as a generic term for such units.

Further new products were now developed to meet current and anticipated future customer needs. By late 1972, Gandalf offered two product lines -- the asynchronous LDS 100 and the synchronous LDS 200 series. A third product, a Private Automatic Computer Exchange (PACX) was designed and built for the computer centre of McGill University in Montreal in that year. The function of a PACX is to handle and direct all incoming calls from terminals to the appropriate class of service required by users from the computer. Its function is similar to that of the Private Branch Exchange (PBX) in the voice telephone network. This product also proved to be successful and consolidated the company's growing reputation in Canada. By mid-1973, Gandalf had sold 2,000 local data sets and seven PACXs.

International Expansion

Throughout this period, the company continued to sell imported U.S. products which complemented its product lines. In an attempt to expand its markets, the company tried to persuade its U.S. supplier to sell Gandalf products in the U.S. The U.S. manufacturer declined to do so, believing, as did its U.S. customers, that no Canadian company could do anything new and useful in electronics. Gandalf therefore opened a warehousing operation in Buffalo, N.Y. and initially sold its products in the U.S. through a distributor -- Penril. The Buffalo operation also included technical staff to provide customers with installation and product servicing and maintenance. The individual who sold most Gandalf products in the U.S. was the distributor's mid-West regional manager, Al Melkerson, based in Chicago. In 1975 he decided to resign his job, so Gandalf hired him and established a U.S. manufacturing and direct sales operation -- Gandalf Sales Inc. (GDI), located in a new facility in Wheeling, a suburb of Chicago. This company was founded as a separate American corporation rather than as a subsidiary of the Canadian parent company. Some stocks in GDI were given to members of the management team hired to run it and this team had complete autonomy over day-to-day operations. This arrangement provided two benefits. First, it elicited commitment from the local management team. since its members could share in the equity growth that would follow successful operations. Second, it enabled Gandalf (through GDI) to raise money in the U.S. without obtaining funding or guarantees from Canadian banks. This U.S. affiliate was licensed to assemble and market the Gandalf product lines in the U.S. and quickly secured an expanding list of new U.S. customers from coast to coast.

In early 1977, Gandalf launched medium distance modems, the LDS 400 series which could transmit data at speeds of up to 4,800 bytes per second (bps) over a range of 50 miles. This breakthrough generated orders for 1,000 LDM 400s in 1977 when Gandalf's total product sales were approaching 30,000 units. By late 1977, more attention was being paid to non-North American markets and a third affiliate, Gandalf Digital Communications Ltd. (Gandig), was established in the U.K. to market Gandalf product lines throughout that country.

Initially in the U.K., Gandalf products were distributed, sold and serviced by Computer and Systems Engineering (CASE) an English company which manufactured products complementary to Gandalf's. Later, however, a conflict of interests developed. First, both Gandalf and CASE wished to develop mutually competitive products, and second, one of the major U.K. customers complained of the poor service being provided on Gandalf products there. This circumstance initiated the establishment of a U.K. based company to both market and manufacture these products.

First, Gandalf hired a field service engineer from CASE to organize a small field service staff. Second, it helped another CASE employee, with a strong marketing background in the European data communications business, to set up his own distributorship -- Master

Systems (Data Products) Ltd. Gandig transferred its U.K. distribution rights to Master Systems and exchanged shares and directorships between the two companies. By this time products had been sold to other large U.K. organizations such as British Steel, the U.K. Atomic Energy Authority and Shell, so that Gandalf was developing a recognizable presence in the U.K. market-place. The technical needs of the market differed, however, from its North American counterpart. The British telephone industry had quite different regulative requirements from the Bell System which, coupled with differences in power supplies, imposed different technical specifications on products to be sold in the U.K. It thereby made economic sense to launch a U.K. manufacturing company. Like its U.S. counterpart, Gandig was structured to allow local management equity participation and substantial autonomy, to attract entrepreneurially motivated individuals to join the company.

The choice of a location for the U.K. manufacturing facility presented some difficulty. The initial preference was to locate it in South Eastern England, close to Heathrow Airport and London and many other companies in the U.K. electronics industry. This search proved to be fruitless, mainly due to frustrating experiences with local government bureaucrats and politicians. The company therefore redirected its search to North Western England in the area around Manchester, which also had an international airport with trans-Atlantic services. A chance encounter between Gandig and Warrington local government representatives led to it locating in the industrial park of the latter town.

Gandalf chose Warrington for the location of its U.K. manufacturing facility for several rasons. First, it was impressed with the support offered by Warrington local government and the local construction industry. Second, as well as being close to Manchester International Airport, Warrington is adjacent to the U.K. motorway network. Third, it is situated mid-way between Manchester and Liverpool, about 15 miles from each of these cities, both with world-recognized educational and cultural institutions. Moreover, Warrington itself enjoys a rural location outside of the 'suburban sprawl' of those large cities and also possesses a local labour pool free from the history of industrial and social strife which has plagued places such as Liverpool. Finally, it is located within an easy commuting drive of agreeable residential areas, such as Chester (an attractive city with a history, as its name implies, going back to Roman times) and with ready access to some of the most beautiful country in England and Wales. Given the positive local support, Gandig was able to start up its U.K. operations, in a temporary plant, within three months of deciding to locate in Warrington. It subsequently moved to a permanent facility nearby and, by 1983, Gandalf was contributing 10% to total corporate revenue with a total work-force of 50-plus.

Thus, by the late 1970s, Gandalf products were being manufactured by affiliates in three countries, at Nepean (a suburb of Ottawa) in Canada, at Chicago in the U.S., and at Warrington in the U.K. A fourth company -- Gandalf Services S.A. -- was also founded in Switzerland as a wholly-owned subsidiary of GDL to serve customers in Continental Europe. Sales were now world-wide. Direct sales forces were employed in North America, whilst distributors were used elsewhere. By 1981, annual revenues had reached $40M (see Exhibit I) and it was recognized that, if continued opportunities for growth were to be exploited, a substantial capital infusion was required. Gandalf decided to 'go public' -- a decision which dictated a corporate restructuring.

Gearing Up for Further Expansion

Given that Gandalf consisted of three largely autonomous affiliates, it was difficult to choose which should be used as a vehicle for a share offering. On the one hand, R&D was centralized in Canada so that GDCL owned all the 'technology' which was licensed to GDI and Gandig for local manufacturing. On the other, the U.S. was obviously the largest market both for Gandalf products and its share offering. What was required was a single corporate entity which embraced both features. In 1981, therefore, Gandalf was restructured into a holding company, Gandalf Technologies Inc. (GTI), and three wholly-owned subsidiaries -- Gandalf Data Ltd. (GDL), a new Canadian entity responsible for Canadian manufacturing and sales, GDI and Gandig. Each of these three national companies still retained its own Board of Directors and considerable autonomy of operation. The Board of Directors of GTI included the CEOs of the three operating companies -- Colin Patterson, Alan Melkerson and (in the U.K.) Michael Glover.

The equity of GTI was divided as follows: 66.5% was retained by Des Cunningham and Colin Patterson and 11.9% shared between the individual managers of the original three companies, based upon each of their original holdings. The remaining 22.6% was sold in a public offering of 2.17 million shares in equal proportions over-the-counter in New York and on the Toronto Stock Exchange at US$10-1/4 and C$12-1/8 per share, to provide a capital infusion of over C$25M.

The decision to go public in late 1981 was made for several other reasons. First, over the ten years of Gandalf's growth, data communications had experienced a corresponding growth and maturing process, to become a billion dollar annual business, and several of its contemporary (and competing) U.S. companies in the industry had already launched successful public stock offerings. Given its continued growth potential, companies with successful track records in the industry could realistically expect favourable responses to such offerings from the stock market. Second, until 1981, Gandalf had funded its growth by re-investing its profits and from short-term bank loans which, by then, had risen to $5M. Thus, the firm was vulnerable to changes in bank short-term loan policies. The alternative source of capital funding -- long-term debt -- appeared unattractive in an era of high interest rates. Third, although the North American economy was in recession, which would depress the market value of Gandalf's shares, there was no reason to suppose that the economy would improve over the next year or so; by which time expansion capital would become an acute need.

After this event, the 1982-83 years proved to be more difficult for the newly structured corporation. The continued recession eroded the growth rate of the industry whilst, at the same time, its billion dollar size plus outstanding further growth potential, coupled with the deregulation of the telecommunications industry in North America and elsewhere, attracted an increasing number of competitors. These ranged from small entrepreneurial companies (such as Develcom of Saskatoon), seeking to replicate Gandalf's success, to the giants like AT&T and Northern Telecom. Tighter competition led to shorter product life successful companies must operate with lean organizations, efficacious R&D and marketing and efficient manufacturing organization and methods. During these years, Gandalf took steps to meet this challenge.

Success in such a rapidly changing and competitive technological environment is obviously dependent upon judicious R&D investments in successful new products. Despite a drop in profit, Gandalf increased its R&D spending by 50% between 1982 and 1983 (see Exhibit I). R&D was centralized in Canada within GDL at Nepean, about a mile from the manufacturing plant, and was responsible for new product development for the whole corporation. Although the loose association of three largely autonomous operating companies was useful in attracting entrepreneurial talent, rather than operating as one $60 million company, Gandalf tended to act as three $20 million companies, which had clear disadvantages. First, it generated problems in identifying new product needs. Marketing staff from each of these three operating companies defined specifications for proposed new products based upon perceptions of their local market needs. Rarely could a consensus on a specification be reached by these three diverse groups. R&D therefore received conflicting requests from marketing. Second, three autonomous operating companies also made it difficult to plan and implement efficiently coordinated manufacturing operations and to develop central purchasing policies. Each of the three companies was purchasing raw materials from its own local sources rather than choosing the best global suppliers and enjoying discounts on bigger orders. Also, Gandalf was investing over $1M in hardware and associated software and liveware to implement a manufacturing planning and control system based upon the MRP (Materials Requirements Planning) approach, which imposes a mandatory requirement on the tight collaboration of the departments and staffs involved. Both these considerations dictated a need for a tighter corporate management structure, and a corporate restructuring was undertaken Spring, 1983.

The three autonomous management teams of the operating companies was replaced by a central Board of Directors in GTI with a President (Des Cunningham) and functional Vice-Presidents, each now with international responsibility for his own function and to whom staff in his functional area in the separate operating companies reported. As VP, Technology Colin Patterson assumed day-to-day responsibility for directing Gandalf R&D/new product development efforts, relinquishing his general management responsibilities as President of GDL, with Alan Melkerson as VP, Marketing coordinating international marketing from Chicago. Two of his immediate priorities were to build up the direct sales force in the U.S. and create a similar one in the U.K., where Gandig was severing its association with Master Systems and selling directly to customers. James Bailey, previously GDL's Canadian manufacturing manager, with an extensive manufacturing management background in the computer industry, was appointed VP, Manufacturing to direct and coordinate production between the three operating companies, whilst Brian Hedges continued as VP, Finance. Through this restructuring Gandalf planned to meet the challenging opportunities of the second half of the 1980s.

R&D

When Colin Patterson asumed the role of VP, Technology he recognized that, until then, R&D projects had been started on an ad hoc basis, so that far more new products were under development than the company had the capability to complete. He spent the first year in his new job reducing commitments -- by cancelling, amalgamating and finishing projects, and refusing to take on new ones. He invented what he calls carrot theory.

As he puts it -- if you have a limited plot of earth and sprinkle it liberally with carrot seed you will cultivate a lot of small thin carrots, because none will have sufficient earth in which to grow. A ruthless weeding-out process is required, to leave just a few of the best young carrots which will grow short and fat quickly. He applied this theory to R&D management.

In the 'weeding-out' process he identified the projects or new product concepts which, if they could be completed on schedule, were the most promising commercially -- that is, were 'short and fat'. He thereby reduced the project load from fifty to thirty, and simultaneously doubled the number of designers in R&D from 35 to 70 in a total R&D complement of 170 people (the balance being support staff).

R&D is primarily oriented towards the development of new products (with very little research), so very few PhDs are employed. The design engineers are equally divided between those with hardware and software backgrounds. Their formal qualifications vary from quite a number with community or technical college training through to people with bachelors or masters degrees in electronics engineering. R&D is mainly located in

Ottawa, so almost all of its staff have Canadian qualifications and experience. However, differences in telecommunications protocols between North America and Europe often imply different design requirements for similar products sold on both continents. Therefore, in 1984, Mr. Patterson set up a European Technology Centre in London, England (currently employing eight people) to perform development catered for the European market.

Since the marketing function is directed from Chicago, despite the existence of an electronic mail system (E mail) connecting all company locations, communication between R&D and marketing is less intimate than it would be if they shared a common location. This is particularly true for Gandalf's European operations. For example, an engineer and salesman from the company may sit down over beers in a pub in London and agree to specifications for a new product idea. These specifications must then be reviewed, perhaps changed, and then approved in both Chicago and Ottawa, before R&D can be initiated in either Ottawa or London. This process can be quite cumbersome, and Mr. Patterson is constantly striving to improve communications between R&D and marketing personnel, both in project selection and in the total R&D/new product introduction process.

The practical implementation of carrot theory requires formal procedures for R&D planning, project selection, review and control. These are supervised by Eric McFee, Manager Information Services in Technology Division. Mr. McFee studied mathematics and physics at university and then qualified as a Registered Industrial Accountant (RIA). He joined Gandalf in 1980, with some 25 years of experience in engineering based companies. He was initially hired as Commercial Planning Officer at Gandalf, responsible for securing R&D and other grants from government agencies. Later he was controller for GDL and assumed his present responsibilities from Colin Patterson when the latter became VP, Technology.

Initial project funding for a maximum of $50,000 is approved fairly informally by the Executive Officers Committee (consisting of Des Cunningham, Colin Patterson, Alan Melkerson, James Bailey and Brian Hedges). This provides sufficient money for a preliminary investigation of an idea for a potential new product or revision of an existing product. The end result of this preliminary investigation is designed as a 'green folder'. This provides the more detailed information required to authorize a major R&D expenditure (over $50,000). This information is submitted by E mail for assessment by appropriate people and approval or rejection by the Executive Officers Committee. If approval is given (also by E mail) it is for a specific sum of money described as the 'authorized amount'.

Approval is followed by the preparation of a conceptual design and detailed project plan. The latter requires a very detailed itemization of individual activities, since no activity must exceed two weeks in duration. The top management commitment implicit in the approval also attracts more attention to the project from individuals throughout the organization (especially from marketing personnel). This often means that specifications are repeatedly revised, based upon these further 'inputs', leading to a revised conceptual design and project plan. Given these more detailed analyses, estimated costs almost invariably increase over those given in the original 'green folder' submission. The revised conceptual design and project plan is submitted for review and further approval (if required) through the project planning software (see below). Despite the cost escalation implicit in the above process, it is believed that R&D staff derive their estimates conscientiously, and that they can be expected to increase when a project is subject to more detailed scrutiny. Cost estimation is viewed as an ongoing process so that budgeted, current future estimates and actual costs are compared throughout the duration of the project. A project is subject to further approval if, at any stage during its life, revised cost estimates exceed previously approved ones by $100,000.

Until recently the project planning software was based upon VISISCHEDULE, an Apple package which performs PERT/COST analyses on individual projects, rather than resource requirements analyses and scheduling on a group of projects. When he started his new job, Eric McFee loaded all project plans onto VISISCHEDULE on an individual project-by-project basis. Once they were all loaded up he was able to aggregate total R&D resource requirement for all projects on a monthly basis, and quickly saw that requirements significantly exceeded the total resources available. Thus, for example, in a given month the total requirements for draftsman-hours signficantly exceeded the man-hours available. This meant that draftsmen were kept very busy, but were repeatedly switched from project to project so that no activitity was completed and a project back-log built up. His exercise confirmed Colin Patterson's earlier observation that the total project portfolio was too large for the R&D capacity available. By reducing the number of projects and increasing the number of R&D staff employed, this back-log was eliminated over a period of a few months.

VISISCHEDULE's inability to handle multi-project scheduling was a disadvantage, so an alternative software package was sought. A package called GCO was finally selected which performs the multi-project scheduling required. All projects were phased onto GCO over January-June, 1985. It incorporates a resource library facility which defines the various resource capacities -- the number of draftsmen and computer aid designers in the drafting department, etc. It can then schedule each individual project based upon its individual resource requirements and the total available.

To compare estimated and actual costs throughout a project's duration, Eric McFee has two departments reporting to him: a Project Planning Department which tells him what is going to happen in terms of a project's expected costs and completion schedule, and an Accounting Department which collects historical project data and tells him what has happened. By comparing both sets of reports he can monitor the progress of projects and identify cost/time overruns which require remedial action. The duration times of projects vary quite widely. The development of a small new product may be completed within six months, whilst a major new product family may take five years before it is ready for transfer to manufacturing. More typical duration times are 18 to 36 months from initial product idea to transfer to manufacturing.

The accelerating rates of change in the electronics, telecommunications and computer industries over the past fifteen years have reduced the PLC's as well as having placed increasing emphasis on the development of systems of compatible rather than individual 'stand-alone' products. Therefore it is important to minimize the new product development time. Fortunately, they have also served to reduce the duration of the R&D process itself. Until recently, the electronics circuits design would be realized with discrete components wire-soldered together (or 'wire-wrapped'). This 'breadboard' model would first be 'debugged' to realize the desired performance specifications, before the design was replicated using printed circuit boards (PCBs). Often, particularly as products were designated to work at higher and higher frequencies, some of these 'bugs' would be properties of the wire connections themselves, rather than of the basic design. This arises because, at high frequencies, a short length of wire has parasitic or 'stray' electronic properties, which generate malfunctions which cannot be distinguished from bugs in the basic design. Thus time would be wasted debugging some malfunctions which would not be present in the final product built from PCBs.

The wire-wrapped breadboard model stage is now being increasingly eliminated from the R&D process. Once the design has been finalized on paper it is physically built using custom tailored PCBs directly, using CAD equipment. These custom tailored PCBs are made by Circtronics, a Gandalf owned subsdidiary also located in Ottawa. Circtronics manufactures both custom tailored and standard PCBs (including two-sided boards which allow components to be mounted on both sides) to order for Gandalf and other companies, and can produce a custom tailored PCB in three days. This means that both the first production prototype can be realized and debugged faster and at least preliminary computer aided design (CAD) specifications will have been established for larger scale manufacturing later. Once the prototype has been debugged and the design proven, it is transferred to the New Product Introduction (NPI) Group in Gandalf's manufacturing facility about a mile away. The resource capacities of the NPI Group are also included in the resource library of the GCO software package, so that the Group's work is also integrated into the overall R&D planning, scheduling and control system. Whenever possible, debugged prototypes are test marketed with selected customers to eliminate any unexpected further bugs that may appear when they are operating in their end-use environments, before transfer to larger scale manufacturing.

Manufacturing

As stated earlier, manufacturing is performed in Ottawa, Canada; Wheeling, Illinois and Warrington, England under the direction of James Bailey, VP, Manufacturing, who is located in Ottawa.

The Ottawa plant is located on Colonnade Road in Nepean, less than a mile from the R&D facility on Slack Road. In 1985 it had about 45,000 square feet of manufacturing capacity plus another 12,000 square feet of office space for both manufacturing and other administrative staff. Further land is available there for expansion so Technology Division and the other corporate functions will move to Colonnade Road, when the lease expires on the Slack Road site in 1986. Wheeling has about 85,000 square feet of capacity, whilst Warrington has over 30,000 square feet which is currently being expanded by a further 20,000 square feet. Manufacturing is essentially a multi-stage batch assembly process and is outlined in Exhibit II. Manufacturing, planning and scheduling for all three plants is centrally coordinated from Ottawa.

Until recently much of the manufacturing process was completed in Ottawa, and the U.S. and U.K. plants used for the final assembly, testing and shipping of products to be sold in their respective markets, to enjoy some economies of scale in manufacturing. This policy has changed, however, as sales have increased in all three countries and the goal is to have each plant perform the total manufacturing process for all the products it sells in its 'own' market. The only exceptions are new products. Pilot runs of new products are first made by the NPI Group, followed by increasing run lengths, all at Colonnade Road. Once all the 'bugs' have been removed from the new product assembly process, the 'know-how' is transferred to Wheeling and Warrington so that the product can be manufactured at these two plants. During the interim period these plants will only complete the final assembly, etc. process as in the past. Technology or 'know-how' transfer is fairly straightforward because most products are manufactured on common, highly-automated assembly lines, so that the 'know-how' is mainly incorporated in new specifications for operating the automated equipment used. Differences in the basic design of a new product will have been specified in the R&D/NPI process described earlier and incorporated in its PCB, IC and discrete components requirements which are the 'raw material inventories' of the overall assembly process. In mid-1985 Colonnade was still manufacturing about 50% of Gandalf total sales output, significantly higher than its Canadian domestic sales which are about 35% of that total. This was for three reasons. First, as mentioned above, the sales volume has only recently made it economically attractive to perform full manufacturing in all three plants separately. Second, many new products were introduced into the market during the year or so before that time, so that Colonnade Road was atypically involved in new product manufacturing introductions. Third, an extensive manufacturing plant automation programme had just been completed first at Colonnade Road and then in turn at Wheeling and Warrington, whose benefits could first be released in the Ottawa plant. The percentage (but not the absolute dollar value) of manufacturing performed in Ottawa is expected to fall as the Wheeling and Warrington plants increase their outputs. The mix of products made in the three plants will likely be broadly identical, because the mix of sales in all the three markets are similar, subject to any differences in communications protocols.

The joint coordination of planning, scheduling and control in all three plants is implemented using a comprehensive MRP systems, which was phased in from 1983 onwards. This can be viewed as the automation of manufacturing management (as against the process) in the plants. The implementation of MRP is recognized to be an expensive and time-consuming process, and it cost Gandalf about $2 million (in hardware, software and training costs) to install the system. Annual operating costs are about $500,000. The software was purchased from N.C.A. Corporation and runs on VAX 705 and 780 and DEC 2060 computers connected to VT 100 emulator visual display terminals (VDTs) located at key workstations and elsewhere throughout the three plants. The network is controlled by a Gandalf PACX and interconnects with the corporate E mail system.

Overall manufacturing planning, scheduling and control for the three plants is the responsibility of June Jordon (Corporate Program Coordinator) using MRP. June Jordan is located in Ottawa and coordinates manufacturing in all three plants through the corporate computer network and E mail. She thus views manufacturing as taking place in one 'notional plant'. Marketing (see later) first prepares an annual so-called 'frozen' forecast of sales broken down by products and countries. This is approved by the Executive Officers Committee and provides the starting basis for annual budgeting and planning. Manufacturing then prepares a 'build' forecast or Master Production Schedule (MPS) which, in turn, is also approved by the above committee. Manufacturing can issue orders to raw material (RM) suppliers based upon lead times of up to six months. This schedule is flexible enough to accommodate departures from the 'frozen' forecast of ± 20%.

Over the year Marketing 'fine tunes' its 'frozen' forecast every month, into monthly 'demands' based upon a 'rolling' three-month forecast (which incorporates firm customer orders) which constitute the 'independent demand' in MRP terminology. Successive monthly manufacturing schedules are then implemented to ensure that all products are built to a replenishment stock level equal to three weeks demand, automatically triggered by the MRP system. The three-week safety stock rule reflects the fact that it takes about three weeks for a given product to pass through the manufacturing process outlined in Exhibit II. Time-phased scheduling is based upon two-week 'time buckets' using lot-for-lot sizing.

Work orders for 'kits' are issued every two weeks. A kit incorporates the MRP bill-of-materials (BOM) explosion for the numbers of components required to assemble a given product lot-size. At the beginning of each week stores staff start to 'parts-pick' the components required for the kits to be issued during the week. Parts-picking is itself partially automated using computer controlled rotating storage racks programmed with the BOM's. These kits are then issued to the manufacturing personnel according to the time-phased schedule for the week. Manufacturing then follows the sequence outlined in Exhibit II. Individual products usually take one to four days to complete each of the five main stages in the manufacturing process depending upon lot sizes. Typically only one run of each product is performed each month. However, if a given product lot size exceeds a four-day manufacturing capacity at any stage, it is broken into two or more lots or manufacturing runs which are performed in different weeks. Thus sometimes products for which there is a high demand may be manufactured in two, three or every week of a month. This ensures that the three-week safety stock levels of all products are maintained.

Given its recent expansions in manufacturing capacities, Gandalf does not face any acute problems of scheduling products through production 'bottlenecks' at the present time. Such potential bottlenecks invariably occur on capitally intensive automated equipment (costing say $200,000). Although the plants generally operate single-shift working, the key expensive automated equipment operates over two to three shifts. When a bottleneck is anticipated at a given point, the equipment is operated over three shifts to eliminate it.

This is inexpensive as it only requires one technician to run it over the whole shift. June Jordan (and others) can readily 'fine tune' the manufacturing schedule to anticipate bottleneck and other problems using the MRP system and E mail. From daily MRP status reports from computer terminals at key stages in the process (see Exhibit II), she monitors the progress of the time-phased schedule, so knows what is happening at all three plants all of the time. She can change it in response to, say, unexpected 'lumpy' demands for a given product and immediately communicate the change through the E mail. All manufacturing staff have access to the same information, so they too can recommend scheduling changes if it is thought that they are needed.

Scheduling obviously requires that standard times be established for each product/operation combination, but formal time study is not used. Time standards are initially established for new products based upon actual times taken for the individual operations. Workers are paid a straight hourly rate so standard times are not required to implement an incentive scheme. A Christmas bonus (which can be quite substantial) is paid to all employees, based upon the corporate annual performance, which provides a formal incentive system. Although the company does not formally exploit the learning/experience curve concept, it is incorporated informally in planning, scheduling and control. Times and costs of all product runs and operations are monitored, both to identify any unacceptable variances and to revise standard times in the light of learning curve improvements with new products. When such a product is transferred to Wheeling or Warrington the disruptive impact on the learning effect is minimal. First, because of the high level of automation in the manufacturing process. Second, because U.S. and U.K. are already familiar with it, having already sold, serviced and (if necessary) repaired it. Equipment automation has caused no employment problems, because Gandalf's steady growth has ensured the workers whose jobs were eliminated could be transferred to other positions within the plants, and the company has never had to lay off employees.

Half of Gandalf PCB requirements (the double-sided boards) is purchased from its subsidiary, Circtronics, located nearby midway between Colonnade Road and Slack Road. The other half is purchased from several vendors. The remaining components and parts are purchased from other suppliers. Circtronics is typically given a three month notice of PCB requirements for established products. Suppliers are reliable in terms of quality and delivery on the whole, except that problems are sometimes experienced with 'dying' and 'new' products. The former sometimes require components (say specific switches) which are no longer sold so the company has to search around for them. The latter sometimes require the most up-to-date components (especially IC's) that are in short supply. Occasionally, such problems constrain the ability of the company to respond quickly to an unexpected urgent quantity order for a product from a customer. MRP quickly enables manufacturing to be rescheduled to accommodate the order, but such responsive action is pointless if essential components cannot be obtained equally quickly. Quality assurance is maintained throughout the manufacturing process. Raw materials are inspected at 'goods inward' before acceptance and inspection stations are located at key points throughout the process (see Exhibit II). All products are subjected to comprehensive functional tests before being transferred to finished goods inventory.

Gandalf's continued quest to find new ways to improve its products and manufacturing processes is illustrated in the decision made, in 1985, to introduce surface mount tchnology (SMT) into the manufacturing process. The project is directed by Gilles Laroche, a very experienced production technologist who, before assuming this position, was Manufacturing Manager for the Colonnade Road plant. SMT is the advanced state-of-the-art approach to securing electronic components onto the PCB substrate. In the traditional method, components are soldered to terminals and/or through holes drilled in the PCB. These holes are about 40 thousandths of an inch in diameter and surrounded by a metal eyelet or collar. Together with the connecting wires to the components, these terminals and holes take up a lot of the space available on a PCB. SMT allows the components to be secured to the surface of the PCB, thus eliminating the holes. This means that components can be placed closer together, especially on two-sided boards. It also allows the smaller components (ICs, resistors, capacitors and inductors) that are now available to be used and reduces the parasitic properties of the circuits mentioned earlier. This means that SMT offers distinct benefits in:

(a) A 75% reduction in the size of a PCB performing a given function. This means that the benefits of the increasing micro-minituarization of components can be more readily realized, leading to size and weight reductions in the final products.

(b) Higher yields and faster assembly times in the manufacturing process because surface mounting is more readily automated and inherently more reliable, leading to reduced costs.

In summary, SMT will enable Gandalf to offer improved products at a lower price to its customers, thus maintaining its competitive position in the marketplace.

Marketing

The marketing function is directed by Alan Melkerson, VP, Marketing, from Wheeling, Illinois. It is organized into geographical areas and product lines (see Exhibit III). Robert Adams is VP, U.K. and European Marketing in Warrington, Verne Fugenbuler is responsible for the U.S. and located in Wheeling, whilst John Wandell, who is responsible for Canada and off-shore markets outside Europe, is based in Nepean. There are two Product Managers, Ed Milbury and Jerry Skeene, whilst Betsy Levela handles corporate advertising.

Ed Milbury has five individual international product line managers who are collectively responsible for marketing Gandalf's products in all of its individual national markets.

'Line drivers' is the term used to describe the original modem product line. After its initial success with short-distance modems, or local data sets (LDS's), Gandalf has designed and manufactured successive generations of modems with enhanced performance features to include medium and long-distance versions. Prices are typically in the $100-$1,000 range.

A significant cost in digital communication networks is that of transmitting data from one point to another. Multiplexers provide a means of substantially reducing this cost, by allowing a transmission line to carry a number of signals or 'messages' simultaneously. Using a multiplexer, data streams from up to 128 computers or terminals may be integrated for transmission over a single line. When they reach the other end of the line, each is directed to its respective destination through a second multiplexer. The price range of multiplexers is $1,000 to $10,000. Short-distance low cost multiplexers are marketed with the prefix GLM (Gandalf Line Miser), whilst the longer-distance and more expensive versions are marketed with the prefix PIN (Private Intelligence Network).

Nowadays customers typically have networks of computers and terminals purchased from different manufacturers that are incompatible. That is, they cannot communicate with each other. The inter-communication facility is provided by the PACX. Gandalf recognized the need for such hardware in the 1970s and pioneered the development of PACXs and the PACXNET concept for distributed networks, which can link several PACXs together. Since then it has marketed a succession of PACX products including, now, its 'top-of-the-line' PACX 2000, which is the responsibility of a separate product line manager. Prices of PACXs start at $30,000 and range up to several hundred thousands of dollars.

Finally, Jerry Skeene is Product Manager with world-wide responsibility for the office automation or communication market segment with both computer data and word processing communication needs. He has no product line managers reporting to him, because his role is to market an integrated range of products in this 'systems' market segment.

Gandalf sees itself as a provider of data communication products for use in communcations networks primarily to satisfy end-customer needs. Initially it exclusively focussed on local and metropolitan networking needs, but increasingly, in geographically small countries (like the U.K.), the term metropolitan can embrace a nation-wide networking capability. A secondary emphasis is placed on the original equipment manufacturer (OEM) and Telco (that is, the national common carriers such as Bell in the U.S. and British Telecom in the U.K.) markets. By primarily concentrating on end-user customers, Gandalf avoids the risk of being dependent upon an intermediate supplier for selling a large proportion of its products. If, say, 50% of sales in a given country are made to the national common carrier as a single customer, there is always the risk that this sales base could suddenly disappear through an abrupt change in the carrier's purchasing policy.

The international product line managers are key linch-pins in Gandalf's organizational structure. Their times are roughly equally divided between coordinating their respective marketing operations world-wide and interacting with Technology Division staff to provide the latter with an awareness of changing market/customer needs. They typically combine both technical and marketing backgrounds. They have either technical marketing backgrounds in Gandalf or other companies, or have previously worked in a technical support function within the company. Many other members of Gandalf's marketing function, at all levels, combine technical and marketing backgrounds. One such example is Robert Adams, VP of U.K. and European Marketing. After graduating from high school in the U.K. he completed a three-year apprenticeship in BT which took him, as he puts it, 'up poles and down holes'. That is, he gained practical experience of much of BT's technical operations. Later he obtained honours and masters degrees in telecommunications engineering. Subsequently he worked in R&D with BT and then in both marketing and sales with Hewlett-Packard (U.K.) for five years, before joining Gandalf. He thus combines technical operations, R&D, sales and marketing in his background. By employing people with such eclectic backgrounds in its marketing function, Gandalf continually seeks to improve communications between R&D and marketing in its geographically dispersed operations.

The importance of this R&D-marketing coupling in the NPI process is emphasized by the fact that Gandalf see themselves as marketing services as much as products. That is, a new product is not just a piece of hardware. Rather than just the 'product' itself it incorporates pre- and post-sales activities, advertising, the product manuals and after-sales servicing. The customer is looking for a piece of hardware that is capable of doing a specific job. However, this capability must be incorporated in a 'total package' which embraces all of the above features. If they are not present the customer will be sceptical of the capability of the product. The product line managers can play important roles in developing both the technical specification and 'total package' for a new product.

Gandalf's distribution and service support systems vary among its different national markets. In North America, the U.K. and the Netherlands, Gandalf employs direct sales forces complemented by field service organizations. Elsewhere in Western Europe, products are still sold through distributors, who must provide the field service support functions. The field sales force in the U.K. has been built up since 1983. Prior to that its products were distributed by Master Systems and the transition from 'distributor' to 'direct sales' took some time to implement, particularly as some of the end customers believed that Master Systems was the manufacturer of Gandalf products. To implement a smooth transition, Gandalf entered into a six-month interim agreement with Master Systems whereby the latter would be credited with the mark-up on sales of designated products regardless of which party made the actual sale. The roles of the field service organizations are somewhat different between Canada and the U.K. as against the U.S. In the two former countries, customers prefer to enter into annual field service contracts to provide on-site maintenance should they experience any problems with the equipment. In the U.S., customers prefer that more modularity be built into the products so that if a particular module breaks down, it can readily and rapidly be replaced to keep the equipment 'up and running'.

Gandalf's competition and market share also vary among the different national markets. In the U.S., where Gandalf can claim only a modest market share of a few percent, it faces several large competitors. Micom is the leading competitor (and, indeed, is Gandalf's number one competitor world-wide) and others include Timeplex, General Datacomm and Infotron. The major computer manufacturers (IBM, DEC, HP and Burroughs) can also be expected to offer increasing competition both in the U.S. and world-wide. In Canada, Gandalf can claim market leadership with Develcom (the Saskatchewan based company) as its major competitor. In the U.K., Gandalf also faces several tough competitors. The leading one is CASE, a U.K. company with a history and background very similar to Gandalf's (recall that CASE was Gandalf's original distributor in the U.K.). Second is BT, which is increasingly seeking to manufacture advanced telecommunications equipment. Micom also sells its products in the U.K. through SCICON, which is a subsidiary of British Petroleum. Other competitors include Gandalf's other former distributor Master Systems, Timeplex, GDC and Infotron. Despite such strong competition, Gandalf believes that it has sold the majority of the PACXs currently installed in the U.K. and its sales are still growing rapidly, both there and in continental Western Europe. The two largest national markets in continental Western Europe are France and West Germany, where market leadership is held by their respective domestic suppliers, Thomson CSF and Siemens. Each European country is 'different' to some extent, because each has its own parochial peculiarities in terms of regulations and other requirements. Apart from its quite substantial size, the Western European market is important for another reason. Over the past decade, Western Europe has been keener than the U.S. to adopt new ideas in data communications technology. For example, the U.K. has led in the adoption of integrated service digital network (ISDN) technology. This means that data communications companies that wish to stay at the leading edge of the technology must first develop and sell their new products in Western Europe. This is one reason why Gandalf has established a European Technology Centre in the London area.

As was stated earlier, Marketing prepares an annual forecast of sales by products and countries. Preparing a reliable forecast is difficult because, quoting Robert Adams:

> "It's a very fast-moving marketplace to be involved in. A very dramatic one of constant change. You never get leadership for very long. You never have 'firsts' for very long and you really have to stay on the ball in it."

In such a turbulent market much depends on judgment and 'gut feel', but Robert Adams is constantly seeking to refine his forecasting to minimize the considerable implicit uncertainties in the situation. This is especially difficult since the recent annual sales growth rate has been 150%, rather than the 50% anticipated. He is currently refining a time series analysis forecasting model, run on a PC, which will provide a three-month 'rolling' forecast of Gandig sales. His goal is to provide extrapolative forecasts, accurate to within ± 20%, to enable Manufacturing to respond to changing demand in a timely manner.

Further Reorganization

By August 1985, it was believed many of the benefits sought in the 1983 corporate restructuring had been achieved, so a revised structure was introduced (see Exhibit IV). Des Cunningham became Chairman and CEO whilst Colin Patterson returned to a general management role as President and COO (Chief Operating Officer). Jan Bartl replaced him as VP of what is now called Product Development (as against Technology) Division. He has a European as well as a North American background, so is sensitive to the needs of the European marketplace. Through these changes, Gandalf was preparing itself for the challenges of the late 1980s and beyond.

Exhibit I

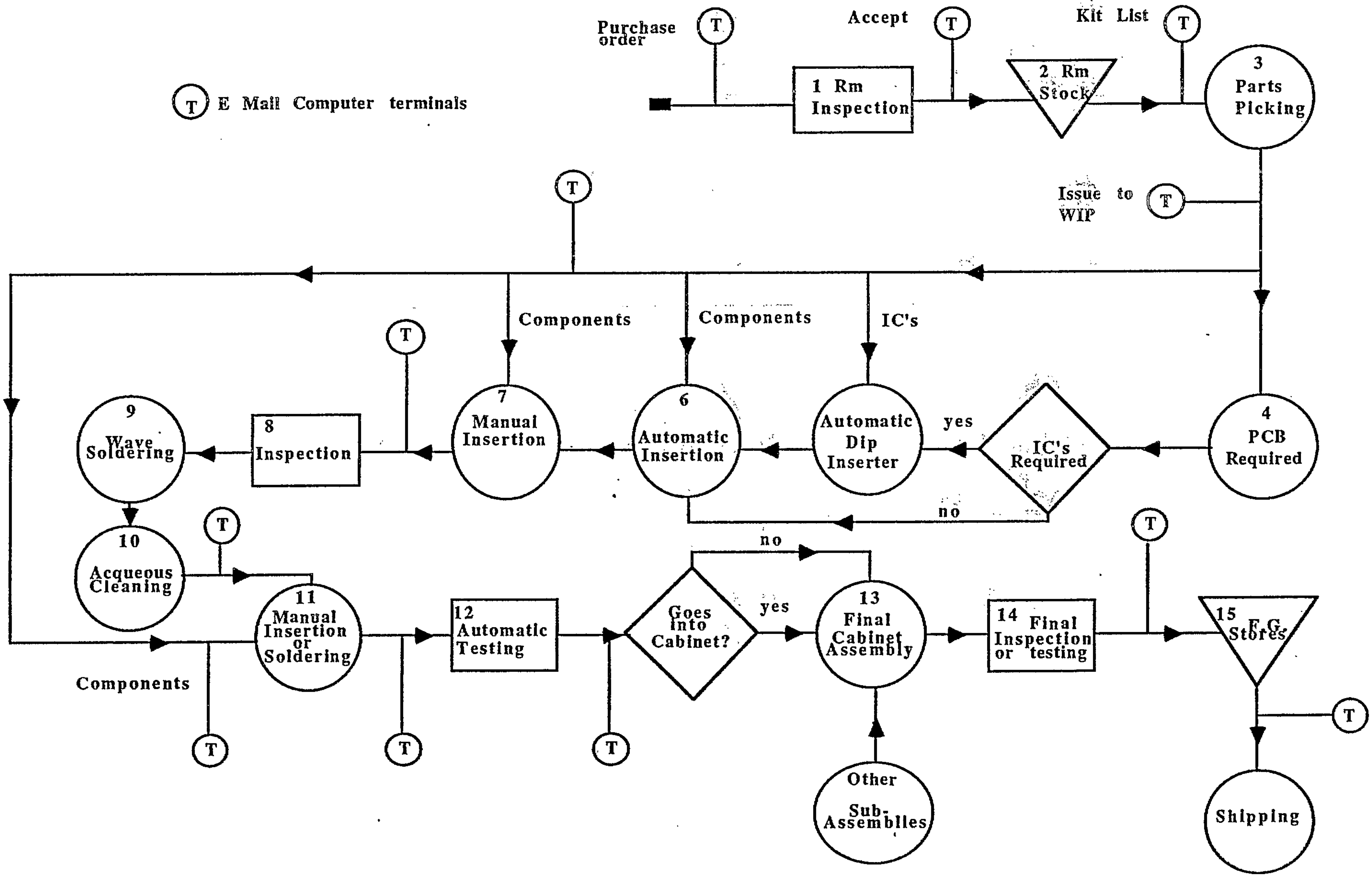
Sources: Corporate Annual Report and others

Year	1978	1979	1980	1981	1982	1983	1984	1985
Revenue	8171	12900	26135	40214	53318	58580	69121	85882
Accounts Receivable	1665	2795	5912	9678	11404	10528	16824	21127
R&D	n.a.	929	1411	2813	4219	6491	9147	11653
Inventories	1607	2851	7467	7661	11000	10850	14323	19454
Long-term Debt	n.a.	n.a.	n.a.	135	507	5454	6453	5439
Net Income	n.a.	n.a.	n.a.	4111	6694	3699	5024	3236

n.a.: not available

Exhibit II

Overall Manfacturing Process for PCB Based Module



1. R.M. inspection to ensure that all components conform to specifications.

2. R.M. stores.

3. Parts picking, kits issued on a daily basis.

4. PCB preparation. Masking, etc. and, if required, modification of PCB's. Sometimes a standard PCB obtained from Circtronics or another vendor needs minor modifications to conform to the specification required. This situation arises either when the small numbers required do not justify the cost of purchasing a custom tailored PCB or an engineering change order (ECO) was made too late for them to be implemented outside the plant without delaying the completion of the product manufacturing run beyond the date specified by the MRP schedule.

5. IC insertion. If they are required, IC's are added to the PCB using an automatic dip inserter.

6. Automatic insertion and clinching of components. Whenever possible the other components are inserted automatically, but some require:

7. Manual insertion and clinching which is performed after the above step. At steps 6 and 7 components are loosely clinched to the board to ensure that they will not fall out.

8. Inspection. All the components which can be wave soldered to the board are now in place. Each board is individually inspected to ensure that all the correct components have been correctly inserted.

9. Wave soldering through a large machine which automatically solders their components to batches of PCB's.

10. Acqueous cleaning through a large automatic 'dish-washing' machine which removes the remaining masking material and solder flux from the boards.

11. Any components which could not be wave soldered are now manually inserted and soldered into place.

12. Automatic testing. Both the board itself and all the components mounted on it are individually tested to ensure that they are working properly. If not, it is repaired at this test-station and re-tested before passing to final inspection and testing or to:

13. Cabinet assembly. Hardware (such as power supplies) is added to the board assembly and incorporated into either a stand-alone or rack-mounted unit which constitutes the final product.

14. Final inspection where either PCB's or cabinet assemblies are subjected to final inspection and functional testing (as against component testing at step 12) to ensure that the finished product conforms to its performance specifications. Providing it does, it is then transferred to:

15. Finished good inventory.

The completion of each of the steps in the above process for a given product is immediately recorded in the MRP system from computer terminals located in the shop floor. Thus June Jordan and other staff have up-to-date records of work-in-progress.

EXHIBIT III

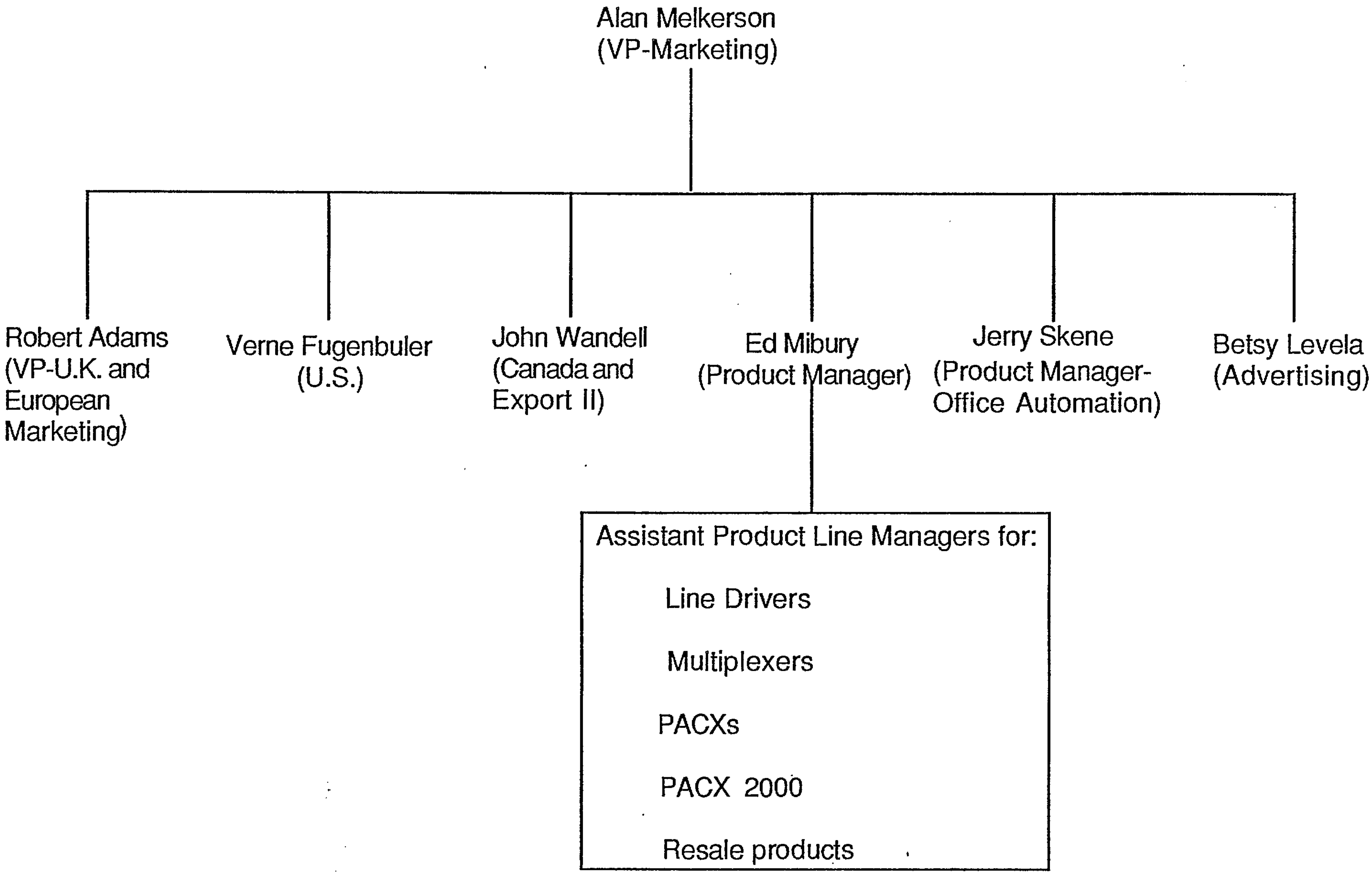
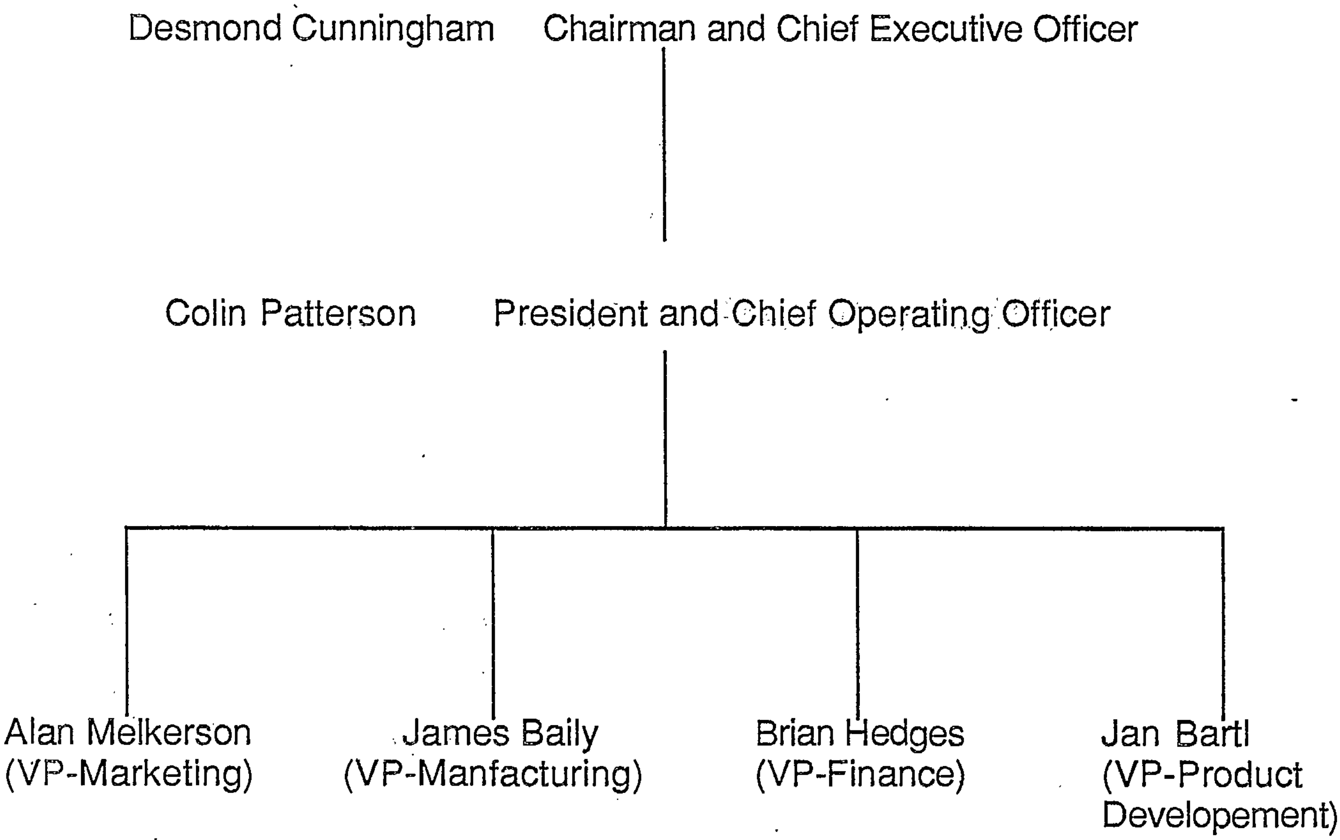

Alan Melkerson
(VP-Marketing)
Robert Adams
(VP-U.K. and
European
Marketing)
Verne Fugenbuler
(U.S.)
John Wandell
(Canada and
Export II)
Ed Mibury
(Product Manager)
Jerry Skene
(Product Manager-
Office Automation)
Betsy Levela
(Advertising)
Assistant Product Line Managers for:
Line Drivers
Multiplexers
PACXs
PACX 2000
Resale products

EXHIBIT IV


Desmond Cunningham
Chairman and Chief Executive Officer
Colin Patterson
President and Chief Operating Officer
Alan Melkerson
(VP-Marketing)
James Baily
(VP-Manfacturing)
Brian Hedges
(VP-Finance)
Jan Bartl
(VP-Product
Developement)

MITEL CORPORATION AND THE SX-2000

> "Most people have the impression that the company bet itself on the SX-2000. This is a dramatic and erroneous perception. What the company bet itself on, and it already knew it had to way back in 1978, was the transition to a digital capability. We grew up in the analog business knowing full well that we had a limited life span before our products would have to start to compete with those with digital capabilities. This does not mean that analog technology has gone away and died, because at the bottom of the PABX market, it is still very competitive with digital in terms of end-customer needs. So long as it stays competitive, that technology will continue to live. But we also had to develop the digital technology. The SX-2000 happened to be the lead product for that. It was the introductory product. It was quickly followed by the G1000, digital capabilities built into the SX-200."
>
> Bob Wright, Former Director of Public/Investor Relations

Bob Wright made these comments when discussing events in Mitel Corporation over the period 1982-85. This had been a particularly difficult period for the still young corporation. Like the human adolescent it was experiencing 'growing pains' of transition to adulthood and maturity. Also, like its human counterpart, its own problems of adolescence received undeserved criticism from some of the media. During its spectacular growth, in the late 1970s and early 1980s, Mitel was the 'blue-eyed boy' of the media and lauded as an exemplar of Canadian

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This case was prepared by Professors Michael Martin and Philip Rosson of Dalhousie University as a basis for class discussion rather than to illustrate effective or ineffective handling of an administrative situation. Some of the data and information have been changed to preserve commercial confidentiality. The authors gratefully acknowledge the financial support of the Federal Department of Regional Industrial Expansion, Office of Industrial Innovation in the development of the case.

achievement in the competitive international 'high-tech' arena. Later, when it was striving to cope with the problems of growth, which is the inevitable lot of the successful young company, some of the media were quick to chronicle its troubles and herald its early demise. They particularly dwelt upon the delays in the completion of the SX-2000 project, suggesting that it was a too ambitious undertaking for the stripling corporation.

Origins and Products

Mitel Corporation was founded in 1973 by Mike Cowpland and Terry Matthews. Mike grew up in Bexhill-on-Sea, England where he was born. His father was a local restaurateur, professional tennis player and both his parents were national-class bridge players who were employed by cruise ship operators to provide bridge tuition to passengers. Mike is no slouch on the tennis court himself, but his bridge-playing skills remain unreported. In 1964, he graduated with a bachelor's degree in electronic engineering (EE) from Imperial College, London. He immediately took a job with Bell-Northern Research (the research arm of Northern Telecom) in Ottawa, but did not anticipate staying in Canada more than a year or so. However, his first secretary at Bell-Northern was a Canadian -- Darlene McDonald -- who shortly afterwards became Darlene Cowpland, so his initial flirtation with Canada blossomed into fruitful marriage both for themselves (Darlene and Mike have two lovely daughters) and for the country. In 1968, Mike Cowpland was transferred to Microsystems International (also in Ottawa) the semiconductor manufacturing subsidiary of Northern Telecom. During this time he also completed a part-time master's degree in Electrical

Engineering at Ottawa's Carleton University and, in 1971, was awarded a National Research Council scholarship to work there full-time for his Ph.D. degree. After completing his Ph.D. research he returned to Microsystems where some of this work was incorporated into a company product.

Terry Matthews was also born in Britain in the same year as Mike, but can claim to be Welsh rather than English. He was born in Newport, South Wales just across the border from England. He also qualified as an electronic engineer and gained initial work experience with the British Post Office in satellite communications electronics. In 1969, he moved to Bell Canada and later to the position of marketing manager at Microsystems, where he met Mike. With similar backgrounds, ages and outlooks, they rapidly became close friends. Among their shared values were a desire to launch an independent business and frustration with what they viewed to be the bureaucratic and slow-moving management of Microsystems.

Whilst still working for Microsystems, they incorporated their first company -- Advance Devices Consultants -- with plans to enter the electronics industry. To generate some cash to pursue this goal they began with a plan to import cordless lawnmowers. Unfortunately, delivery of the first three lawnmowers was delayed and they arrived at the peak of the Ottawa winter, so that venture proved to be farcical. By then they had left Microsystems and decided that the title for their company was perhaps ill-chosen. They therefore changed it to Mitel as a partial acronym of "Mike and Terry electronics", and considered other product possibilities.

One possibility considered was a telephone amplifier and integrated PA system, but no market was found for such a system. By then they had spent $2,000 of their limited savings and faced an acute need to identify a viable product idea, based upon their joint strengths. Matthews' expertise was primarily in telecommunications technical marketing, with experience which provided insights into market needs as well as a network of potential customer contacts. In contrast, Cowpland's expertise and experience were in the design of telecommunications hardware, coupled with increasing management responsibilities. His thesis work provided a theoretical base upon which he would design Mitel's first marketable product. This was a tone receiver -- an electronic device for converting the musical tones generated by the keys of touch telephone hand-sets into electronic signals which would be recognized by other equipment in the telephone system.

Mitel first began operations in 1973 in a couple of offices and a laboratory rented in the Junior Chamber of Commerce building in Kanata (later to become the high-tech suburb of Ottawa). Its initial work force was eight, including Mike, Terry, Darlene (who typed the letters, etc.) and Tom McLeod, who had worked for Mike at Microsystems. Their personal savings had been reduced to $5,000 by their earlier unsuccessful venture, so they could not afford to make the product with integrated circuits (ICs). Instead, Mike, Tom and their four assistants soldered together traditional components in a small-scale 'DIY Heathkit operation', whilst Terry telephoned his contacts throughout the North American market extolling the virtues of the new product. His claims were justified by the fact that in 1974 Plessey (a major supplier of telecommunications equipment in the U.K. and several other countries) placed an order for 100 units. Mitel lacked the working capital to finance this order so sold a 25% stake in the equity of the company to a group of Ottawa and Ontario businessmen for $100,000.

In 1975, Mitel combined tone receiver and large scale integrated (LSI) circuit technology to produce a tone-to-pulse converter permitting telephone companies to offer touch-tone phones to subscribers in areas serviced by electro-mechanical exchange equipment designed to receive signals from rotary phones only. The inventive design of their product enabled Mike to manufacture it from $30 worth of components and sell it for $150, as compared with a $300 priced product currently on offer. It satisfied a real market need because, with it, telephone companies could quickly offer touch-tone services without expensive exchange equipment replacement. Its success generated a positive cash-flow which was re-invested in further corporate development, beginning with the purchase of an IC manufacturing facility -- Siltek International in Bromont, Quebec -- in 1976.

Mitel recognized that the success of their tone-to-pulse converter was primarily based upon the superior design features of its LSI technology and that they had the potential to generate other competitive telecommunications products based upon this generic technology. It therefore appeared advantageous for Mitel to acquire its own chip manufacturing facility, rather than rely upon the purchase of custom-designed chips from outside suppliers. Siltek had been manufacturing semiconductor chips for digital watches, games and other consumer electronics products but without achieving profitability in this very competitive sector of the electronics industry. The purchase appeal of the ailing Siltek was further enhanced by the fact that one of its talented engineers, Dr. Alan Aitken, had developed a proprietary process for manufacturing metal oxide semiconductor ICs, known as the ISO-CMOS process.

This was particularly suited to telecommunications applications because it provided a chip with:

(i) A high density of electronic components suited to both analog and digital applications.

(ii) An improved facility to design higher speed switching circuits.

(iii) A considerable reduction in power consumption.

This acquisition provided the opportunity for Mitel to enter the PABX (Private Automatic Branch Exchange) market by developing a series of products -- the first being the SX-200 SUPERSWITCH which was launched in 1978. The novel hardware incorporated into the SX-200 was an analog crosspoint LSI chip which was based upon the 'leading-edge' ISO-CMOS technology. The superiority of this technology is demonstrated by the fact that it is now sourced under licence to a number of other major organizations, making it the number one multi-sourced choice for new designs of PBXs.

The SX-200 was designed to provide small to medium sized organizations (e.g. smaller businesses and hotels/motels) with PABXs superior to those currently available. The PABXs then available were primarily designed for larger telephone users and were large bulky products with relatively high power consumptions and a limited range of product features. The SX-200 was comparatively small with a significantly reduced power consumption. It offered up to 150 different features which could be essentially custom-tailored to the organization's needs through the incorporation of different software packages. The current SX-200 has 208 ports (up from 175 when it was first launched) and in a typical configuration provides 150 extension and 24 trunk lines. The launch of the SX-200 was followed shortly afterwards by the SX-100. This was virtually a half-sized version of the SX-200, and therefore suitable for smaller organizations, since it incorporated all the software but half the hardware of the SX-200.

The next range of PABXs was again based upon improved solid-state technology developed by the (now) in-house Mitel Semiconductor Division. This was a thick film hybrid process which incorporated IC semiconductor technology into a ceramic substrate to produce electronic circuits mid-way in size between printed circuit boards and ICs. This success enabled the company (by 1982) to offer a range of even smaller PABXs, the SX-20, SX-10 and Super 10 for use in smaller organizations.

Corporate Evolution

Exhibit I illustrates the dramatic growth of Mitel over the first decade of its existence. A growth which has been based upon the successful penetration of international telecommunications markets and the evolution of the company into a publicly listed (on the Toronto, Montreal, New York and London stock exchanges) multinational corporation, with manufacturing operations in several countries. The revolutionary technological changes, coupled with the deregulation of telecommunications in North America and elsewhere, have provided opportunities for new entrants into the industry. During its first decade Mitel had exploited such opportunities to capture a major share of the total PABX market in the U.S. and become the largest non-Bell competitor within it.

Mitel 'went public' in 1979 to finance its sustained growth. Initially one million shares were sold on the Toronto Stock Exchange, to be followed by a further 900,000 in 1981. Three-quarters of a million shares were sold on the Montreal Stock Exchange in 1980 and 2.9 million on the New York Stock Exchange in 1981. The first million shares in Toronto were sold at an average price of just over C$9.70 per share and since then Mitel's share price has fluctuated widely during varying corporate fortunes caused by the recessionary climate of the first half of the 1980s and delays in the SX-2000 project (see later). The present corporate structure and officers is shown in Exhibit II with seven national operating companies linked to the present corporation in Canada through a holding company in the Netherlands.

Marketing Operations

Until fairly recently, telephone systems throughout the world have had private or public regulated regional or national monopolies, such as those run by AT&T and the Bell System in the U.S., Bell Canada in Canada, and the Post Office in the U.K. In the larger developed countries those national monopolists have typically purchased their equipment from a single dominant or two or three oligopolistic national manufacturers, such as Western Electric in the U.S., Northern Telecom in Canada, and Plessey and GEC in the U.K. The telephone systems in the developing countries and some of the smaller developed countries were also typically based upon one of the larger national systems, so each purchased equipment from the 'parent's' suppliers. Thus, for example, the former colonies of Britain and France have 'British' and 'French' systems, and have historically purchased equipment from British and French suppliers respectively.

The rapid technological changes now occurring which are subsuming telephone systems into more sophisticated (but as yet ill-defined) telecommunications systems, coupled with the deregulation and 'privatization' of national services, has created the fluid market opportunities exploited by Mitel. One can roughly define three categories of end-users for Mitel's products:

(i) The providers of telecommunications services, for miscellaneous products.

(ii) Large to small organizations for PABX products (including now the SX-2000).

(iii) Other telecommunications equipment manufacturers, for ICs and other semiconductor products.

Mitel uses a combination of dealers, distributors or agents, and direct selling to reach these end-users. It has authorized dealers, distributors or agents throughout the world, and also over 30 sales and servicing offices throughout North America, Western Europe and the Far East (see Exhibit II). In some cases it sells product to the providers ((i) above) as original equipment manufactures (OEMs).

For example, Mitel has sold many SX-200 units to British Telecom (BT), the U.K. provider, which is now separate from the British Post Office and was recently 'privatized'. A version of the SX-200 is thus sold by British Telecom as the Regent, and as with this example, the generic product is often modified (usually in its software rather than hardware) to meet local specifications. Selling products to OEMs has proved to be a useful vehicle for building up Mitel's credibility in parochial off-shore markets, but it does mean that its salesmen have to compete with their own products sold through OEMs and distributors. All sales efforts are backed up with extensive advertising in appropriate technical, business and consumer periodicals and newspapers, as well as exhibitions and professional conferences and business fairs. Such promotions are important information communication vehicles because, with the rapid rate of technical change in the industry, product performances and specifications need continual updating.

Manufacturing Operations

The company moved from its original location in Kanata in 1975, first to a warehouse backed up by seventy trailers and then to a permanent site in 1979. This currently houses the corporate headquarters and some manufacturing which is now performed world-wide (see Exhibit II). PABXs are also manufactured and sold under licence in Eastern Bloc countries by domestic organizations such as Tesla of Prague, Czechoslovakia. As well as developing improved process technology Mitel has also applied CAD/CAM techniques, coupled with a Japanese approach to quality, to maximize the efficiency, reliability and yields from its manufacturing operations.

R&D

Ninety percent of R&D is performed at Kanata, and the balance about equally divided between the U.S. and U.K. The latter two facilities primarily adapt products to the local requirements of their own domestic and related markets. Their work is mainly custom-tailored software design. Concentration of most of the R&D effort in Canada maintains good communication links with marketing and manufacturing to ensure that new product developments focus on the corporate perception of world-wide needs. The existence of smaller R&D efforts in the other two countries protects the corporation from losing sight of the local needs of the large U.S. and European markets.

R&D expenditures have risen dramatically over the years as the corporation has grown (see Exhibit I), reaching a peak of $68.3 million in 1984 with the large R&D investment on the SX-2000 project (see later). The Canadian government, keen to buttress domestic industrial R&D capabilities, has provided general financial support during these years. The corporation received a grant of $21 million from the Special Electronics Programme of the Enterprise Development Board to help Mitel to advance its leading-edge capabilities in large scale integrated (LSI) and very large scale integrated (VLSI) circuit technologies. Notable support has also been provided by the National Research Council (NRC) through its Industrial Research Assistance Programme (IRAP).

Human Resources

As with many new technology-based businesses, Mitel believes that corporate achievement is individual achievement writ large. It therefore places great emphasis on the participation and personal development of its employees. Everyone is on first name terms and management maintains an 'open door' policy towards all staff. As the corporation grows, its founders and senior managers recognize the importance of maintaining good communication between its various levels and functional departments. Although a formal hierarchical structure exists to facilitate planning, accountability and control, information communication outside of this formal structure is encouraged to ameliorate the harmful impacts of unavoidable bureaucratic procedures. Most offices are open-plan and production facilities are laid out to reproduce an office-like environment with brightly lit ceilings, carpeted floors, etc. whenever possible. Exceptions are in semiconductor manufacturing, where the technology of IC and thick film hybrid fabrication dictates a dust and particle free atmosphere far 'cleaner' than that required in a hospital operating room.

Mitel offers a comprehensive benefit package, profit sharing and stock purchase options to all employees after six months service. Personnel development is encouraged through internal and extension courses related to organizational needs (for which the company will reimburse the fees once the student has passed). In Kanata an 'evening' masters degree in engineering is currently available, sponsored by Kanata high-tech training levies. New positions created by corporate growth are first advertised internally to encourage internal promotion, before they are advertised externally. In return, the corporation looks for a high level of personal commitment from its employees.

Corporate Retrenchment 1982-85

By 1981 Mitel, after enjoying seven years of phenomenal growth, faced some real challenges. First, the world economy was moving into another recession and the corporation was facing increasing competition in its markets. Second, the size and complexity of the new $100 million plus a year corporation demanded the introduction of more formal management systems and procedures. Third, the decision of whether and how to 'digitalize' the product range had now to be taken.

Mitel's rapid growth began during the 1975 recession which did not appear adversely to affect its sales, which were only constrained by the firm's ability to grow and manufacture more and more products for the 'hungry' marketplace. This experience created the impression that the PABX market was 'recession proof'. When the 1981 recession began, Mitel's initial reaction was to follow the same strategy that had proved to be successful six years earlier. That is, continue an aggressive strategy of sales growth to accelerate right through it. It took a little time for the corporation to recognize that the new recession was different. First, that it was going to be longer and deeper than the earlier one and, second, that, by now, Mitel was facing increasing price and performance competition for its products in the marketplace. This recognition dictated a need for an attitude change within the organization.

Until 1981 emphasis had concentrated on sustained fast growth whereby everyone sought to grow with the organization and turn out increasing numbers of good quality products regardless of cost and efficiency considerations. From 1982, as market growth slowed down and working capital became the commodity in shortest supply, the emphasis shifted to corporate rationalization, cost control, and the introduction of large-company mature-management skills. Being short of these skills in-house, Mitel began a deliberate policy of hiring experienced people from mature organizations in all management levels and areas. New corporate board members were David Golden (Chairman of Telesat), Jack Fox (a VP of Western Union), Graham Miller (President and CEO of LTX of Boston), Albert Gnat (a partner of the legal firm Lang, Michener), and Anthony Griffiths (a partner at Connor and Clark and former President of Canadian Cable Systems) who is now President and CEO of Mitel Corporation (see later). New senior managers were recruited from IT&T, Northern Telecom, BT and Motorola as well as other mature technology-based corporations, backed up by appointments at other levels including young MBAs to bring in new ideas from the Business Schools. No attempt was made to recruit a team of corporate 'hatchet-men'. Rather people were hired who combined management maturity and experience with the perception and interpersonal sensitivity to help Mitel's existing staff to develop their own management skills.

One example is George Gilmore, who was hired originally as VP of strategic operations planning and was recently named President and CEO of Mitel Datacom. He is a turnaround management specialist and, as a former partner in McKinsey and Co., he has successfully enacted this role in five other corporations. Mr. Gilmore has been initially concerned with reducing Mitel's costs through the rationalization of its manufacturing operations and improved inventory control methods. As a result, some manufacturing plants have been sold in North America and the Irish Republic whilst expansion plans elsewhere have been cancelled. Inventory requirements are being systematically reduced through improved forecasting and the introduction of computerized just-in-time (JIT) systems, to replace the materials requirements planning (MRP) systems used in the past. Comprehensive productivity improvement programmes are being applied throughout the corporation. Quality assurance has always been good, but now more emphasis is being placed on designing products for ease of servicing and maintenance (see later).

It was taking some time for the results of all of these efforts to be reflected in the corporation's financial performance but, despite various difficulties, Mitel's sales had still tripled between 1981 and 1985 (see Exhibit I). Moreover, it had developed and launched its first digital products.

Digitalizing the Product Range

By 1979, Mitel had recognized that the decision when and how to go 'digital' was fast approaching. Although sales of its analog based PABXs were expected to continue to grow rapidly, it was anticipated that by the mid 1980s competitors would be marketing PABXs incorporating digital processing capabilities which would increasingly supersede purely analog versions. By then, customers would be looking for exchanges which could interconnect both voice telephone extensions and computers/terminals in local area networks (LANs). Although the rate and degree of convergence of analog and digital technologies was then (and still is) much debated, Mitel believed that 'days' for entirely analog PABXs were 'numbered', particularly as in the longer-term future even voice signals would be transmitted from one telephone to the other digitally. In other words, analog manufacturers had either to innovate digital technology or slowly die.

The key to developing a digital PABX capability was in IC hardware and Mitel was potentially in good shape in this respect. As was stated earlier, the success of the SX-200 and smaller PABXs had been grounded on the purchase of Siltek International and the acquisition of the proprietary ISO-CMOS process for manufacturing LSI circuit chips. From 1976 Mitel built upon the ISO-CMOS technology to market its products, probably developing the most advanced combination of silicon based hybrid manufacturing technologies in the world. This has continuously enabled it to improve both the hardware and software features of its products. For example, the number of extension lines per printed card (that is, the card which may be inserted into the PABX to increase the latter's extensions capacity as the customer's telecommunications traffic increases) has been increased from four to twenty-four. Also products have been designed on a modular basis and combined with suitable diagnostics software to provide the best possible after-sales maintenance and servicing for the products. The first step therefore was to develop the IC hardware needed to provide similar features in a digital PABX. This development work was begun in 1980, leading to the realization of the DX digital cross-point switching chip using the ISO-CMOS process, which provided the basic building block for the IC hardware for digital-analog conversion and interfacing between the modules in a PABX.

Once this basic hardware had been realized, Mitel could now launch the development of digital PABXs and faced three interrelated issues. First, success to date had been built upon its deep penetration of the medium/small PABX (with 150 down to two lines or extensions per exchange) market segment with superior state-of-the-art products using analog technology. Although sales of these products could be expected to continue to grow (as they did), the corporation recognized that, by the mid 1980s, state-of-the-art PABXs would be based upon digital technology. Second, when Mitel entered this market segment in 1978 there had been no more than 10-20 competitors world-wide. It could be anticipated, however, that the growth of this multi-billion dollar per year market segment, coupled with the opportunities for entry created by telecommunication deregulation, would attract a host of entrepreneurial start-up firms. (This indeed proved to be so because, by 1985, it was estimated that there were at least 150-200 companies offering medium/small PABXs for sale.) Third, this market segment, though large in dollar terms, constituted only half of the total PABX market. The other half is the large PABX (with between 400 and 10,000 extension lines) market segment and this was expected to grow even more rapidly than its small/medium counterpart and become the central hardware facility for the so-called 'office-of-the-future' offering a combination of voice and digital data transmission features.

Mitel therefore faced two options: first, to remain in the small/ medium PABX segment, defend its market share against increasingly crowded competition by phasing in the introduction of digital features into its existing products. This option would be less demanding of R&D, manufacturing and marketing, since Mitel would be defending an already well-entrenched market share and reputation. Given its past record coupled with its recently acquired digital hardware know-how, it could be anticipated that the corporation would be able to maintain its competitive edge in technology.

The second option was to enter the large PABX segment by developing a completely new product based upon state-of-the-art digital technology. This option was attractive for several reasons. It doubled the corporation's target market size and hence its growth potential. Like its major competitors, it would enjoy world-wide recognition as a designer and manufacturer of the complete range of PABXs including the more prestigious large ones, particularly if its large exchange were as well-received as the SX-200. Also it would provide an entry into the potentially lucrative office automation market and all that that implied in the years ahead. Finally, the further digital technology (especially software) know-how which would have to be developed in-house to design a state-of-the-art large PABX would provide a core of expertise which could be exploited in 'digitalizing' its smaller counterparts.

No one in Mitel can recall how long was spent in ruminating between these two implicit alternatives or if, indeed, they were consciously considered at all. The design of the DX chip was completed in 1980 by no more than a half-dozen people and the preliminary design outline and specification for a large PABX was begun in 1981. Up to fifty people were involved at this stage. The decision to enter the large PABX business, that is, to build the SX-2000, was taken at this time. Mitel announced the decision to build the SX-2000 in Spring 1982, stating that its market launch would begin in a year's time. This estimate of market launch date was based upon the corporation's previous experience of the times taken to develop new products and proved to be unduly optimistic. At that time the corporation underestimated the size and complexity of its challenging task, when compared to its smaller PABXs. As one company spokesperson puts it:

> "I don't believe that the SX-2000 was a year and a half late, so much as our 'mouth' was a year and a half too early. We were very naive in how fast we could produce the product, not realizing the project management problems we would encounter. Even so, we have taken three and a half years to do what most companies have taken at least twice or three times as long to accomplish."

Project Management and the SX-2000

The SX-2000 was conceived as a central 'workhorse' for the 'office-of-the-future' with the capacity to handle voice and data communications, office automation and electronic mail. Its physical specification is outlined in Exhibit III.

Although the design and development of the SX-2000's hardware was a very considerable task, by far the bigger technical challenge lay in its software design and development, which was different from that required for the SX-200 and smaller analog PABXs. These earlier products had required control software essentially based upon successive lines of instructions to implement a certain set of PABX user-features and written in assembler coded programs. The software requirements of the SX-2000 were conceptually different, involving much greater logical complexity and many, many more lines of instructions broken into a series of program modules which had to 'fit together'. This not only applied to the software needed to implement the user-features required, but also to the internal operating systems needed to drive what is, in effect, an internal computer-based PABX. Traditional software is typically written for batch data-processing on mainframe machines which is completely different from that needed for the SX-2000, which is a real-time transaction processor. In batch data-processing (for example, a customer billing system), individual users' data are processed simultaneously, essentially from a shared data base. The latter systems require more specialized and sophisticated software, and software engineers experienced in the former lack the experience to write software in the latter field.

Mitel's expertise was mainly in hardware engineering when the SX-2000 project got underway and, given the above considerations, many new R&D staff were recruited from 1981 onwards. Since the number of individuals available with the specialist's software writing skills required was not large, recruiting them was quite difficult, but many joined Mitel attracted by the challenge the SX-2000 presented. The largest single source of experienced people was Bell Northern Research (BNR). The number working on the project reached a peak of about 400 (including ancillary personnel) in early 1984. This number was approximately equally divided between hardware and software personnel. By Summer 1985 the number was substantially reduced, and the staff released transferred to other projects or sought new challenges elsewhere. By then the hardware development had been virtually completed and the majority of the staff still working on the project were software engineers.

Typical of the experienced people who joined the team is Roger Magoon, now Director of R&D Strategy for Mitel. He obtained a bachelors degree in mathematics from Queens University and then a masters degree in mathematics and systems engineering from Carleton University. He worked for several years on data communication products software development at BNR, before joining the SX-2000 software development team in 1981. After two years he moved into a more general role exploring future enhancements for the SX-2000 and is now directing similar efforts for the full Mitel product range. The software was initially written and de-bugged on VAX computers using PASCAL and compiled into object code language which was then downloaded onto the SX-2000.

Just as the technological complexity of the SX-2000 project as compared to its predecessors presented an immense challenge, so did its overall management, because of the number of personnel involved. Until that time, the largest project team size had been employed on the SX-200 and had numbered about twenty people. Teams of this size or smaller can communicate readily and informally, and collaborate on an ad hoc basis to achieve agreed goals. This informal approach had worked well in the past, especially when Mitel was enjoying its early successes. Large project teams of 400 people demand more formal management approaches, however. Lacking this large scale project experience R&D management were slow to recognize the need for these approaches. Moreover, once the need was recognized, since Mitel's success had been built upon the creative efforts of talented individuals in an informal entrepreneurial climate, management were understandably reluctant to introduce them, fearing that they might stifle this creativity. It was in 1982, when these problems were just being faced, that IBM and Mitel began to explore the possibility of a collaborative venture based upon the SX-2000.

At that time IBM were planning to enter the telecommunications market in January 1984, when deregulation and the divestiture of AT&T would be implemented in the U.S. IBM were therefore looking for a large PABX which could be incorporated, as an OEM product, into their integrated telecommunications products range. The '2000' was an attractive possibility because it constituted an advanced state-of-the-art exchange being developed by a still young company that had quickly established an enviable reputation in its field. The possible deal was also attractive to Mitel because, if IBM successfully penetrated the telecommunications market, sales of their version of the '2000' could prove to be very large -- realistically as much as a half-billion dollars per year. However, and in the event the potential deal was not completed and IBM subsequently purchased Rolm of California to source its PABXs. Nevertheless, the IBM-Mitel discussions which took place in 1982/83 were most useful to Mitel in managing the SX-2000 project. The IBM staff involved in these discussions were very knowledgeable and experienced in the management of large-scale projects. They helpfully provided Mitel with much useful advice. For example, although Mitel was using PERT type networks to schedule and control the project, their staff lacked the prior experience to estimate realistically the duration times of some of the software development activities involved. Based upon their own vast experience in such work, IBM staff had developed useful 'rules of thumb' to estimate the time needed to write and de-bug a given block of software and openly provided Mitel with advice of this kind, as well as on other aspects of managing the project.

Once the project and basic software had been developed, tested and proved, production and field trials of the first prototype could begin, whilst software development continued. As with computers, the first prototype was field tested and then market launched whilst software was continuously developed and upgraded in the light of field experiences and evolving end-user needs. The first field trial at a customer site was performed in nearby Revenue Canada in Ottawa. Four further field trials were performed in late 1983 at customer sites in the U.K. to obtain U.K. certification of the product from BT. This certification provided a 'Good Housekeeping Seal of Approval' for the SX-2000 in the U.K. telecommunications market. Similar field site trials were also performed in the U.S. The formal market launch date was announced as January 1, 1984. Facilities and procedures for full-scale manufacturing were then designed and installed in Kanata. This work too presented a substantial challenge because Mitel lacked experience of manufacturing such a large complex product. The manufacturing process takes three months and the facilities were designed to complete up to two units per day. Units are made to customer order. By mid 1985, the cumulative R&D costs incurred exceeded $80 million.

Marketing the SX-2000

The market for large PABXs is self-evident -- until recently, it was any large public or private sector organizations (such as government agencies, hospitals, corporations and hotels) with a large number of 'voice' telephone extensions. Increasingly nowadays the organizations also require 'data' extensions, such as word-processing workstations, mainframe/minicomputers and terminals, microcomputers and telex stations. As stated earlier, with the rapid evolution of microelectronic and information technologies and with it the potential future convergence of analog/voice and digital/data processing and transmission technologies, the large PABX can be expected to become the linch-pin of the office-of-the-future. The total PABX market is large. One source* estimated the total

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* International Data Corporation, "The PBX Market," Automated Business Communications, Waltham, Mass.: 1981.

installed PABX base in the U.S. in 1985 as $18.2 billion with sales of $2.9 billion expected in 1986. Half of this market demand is for large PABXs requiring 400-10,000 lines. Most of this demand is in the 400-4,000 line range and it then tails off to an upper limit of 10,000 lines.

Small PABXs, and increasingly medium PABXs such as the SX-200, are commodity products which can be purchased off the shelf from telephone companies, dealers or manufacturers, like the telephone hand-set. In contrast, the large PABX is a 'big-ticket' customer purchase -- the SX-2000 typically costs the customer $200,000 to $250,000 depending upon the number of lines and user features required. It therefore requires a different sales approach. Given its price tag, the purchasing decision is usually made at the top management level of the organization (say the Board of Directors in a private company) based upon advice provided by its internal specialists, including computer staff. Thus the 'purchaser' is technically sophisticated and looks at price per line installed (which will continue to fall as the product progresses down the experience curve and is currently about $200), the end-user features provided and the credibility/price of service and maintenance agreements. In other words, the selling process for an SX-2000 resembles that for a mini or even mainframe computer.

From its inception, Mitel recognized that the SX-2000 must be competitive in terms of ease of service and maintenance and user features, as well as selling price. Much of the R&D effort went into designing the hardware and software to ensure this. Hardware was designed and built on a modular basis so that a serviceman could diagnose and repair a fault in a customer's installation by, say, replacing a faulty module from a set of spares carried in his service van. Marketing staff carefully analyzed end-user needs and, throughout its development and field trials, they interacted continuously with R&D staff to ensure that this goal could be achieved. This is another reason why development took longer than anticipated, but it ensured that the SX-2000 could be sold as a fully supported product.

There are four alternative sales/distribution channels for the product:

(i) Indirect sales through telephone common carriers (such as Bell in North America and BT in the UK).

(ii) Indirect sales (as an OEM product) through interconnect manufacturers of telecommunications equipment, including computer manufacturers.

(iii) Indirect sales through authorized dealers/distributors.

(iv) Direct sales to the final customers.

Mitel is using, or planning to use, all four channels in selling the SX-2000 world-wide, with the 'mix' varying from country to country. By mid 1985, 133 SX-2000s had been installed, including 58 in the U.S., 30 in Canada and the remainder in the U.K. and New Zealand, and none of Mitel's customers had any serious complaints about the product. The largest sales had been reached in the U.K. as an OEM product for International Computers Limited (ICL) as the DNX-2000. It is also sold by BT. The major marketing problem experienced has been in establishing the best selling 'mix' for non-OEM versions of the product, particularly in the U.S.

Non-OEM versions of Mitel's smaller PABXs (including the SX-200) are sold primarily through major distributors or supply houses such as North Supply, Greybar and Alltel (in the U.S.) and Norton (in the U.K.).

These distributors have, in turn, sold them to smaller dealers who have sold them to their end-customers. That is, historically Mitel has had little direct contact with the end users of its products, since the limited after sales services required could be provided by distributors and dealers. Purchasers of the SX-2000 are looking for a close relationship with its manufacturer for two reasons. First, given that they are spending upwards of $250,000 for the equipment, they naturally expect access to a first-class after-sales service from the manufacturer itself. Second, as with computers, purchasers look for rapid access to manufacturers' software upgrades and enhancements. In other words, customers are not buying just an expensive box of hardware, but a comfort level or feeling of stability and long service with which they can feel secure. The distribution system must provide this. Most Canadian sales to date have been made through large dealers such as GTE and GH Communications. The SX-2000 was approved by Bell Canada in 1985, so future sales are anticipated through Bell and the other telephone operating companies in the Provinces.

The most difficult market to penetrate has been in the U.S. The initial strategy was to sign up large rather than small dealers, establishing mutually acceptable agreements for the joint financing of the sales of the product and for the joint provision of the after-sales services required. One such agreement was reached with RCA Service Co. (a subsidiary of the Radio Corporation of America). It was thought that only large dealers could provide the after-sales service credibility that purchasers required. However, operational experience with the SX-2000s already installed showed that the installation, service and maintenance requirements were much lower than anticipated -- a reflection of efforts put into the product development cited earlier. So Mitel have now therefore decided to sign up smaller dealers (including some they had earlier ignored) to sell the product. Under these arrangements, Mitel itself guarantees the after-sales services to the end purchasers, but subcontracts the work to the dealers whenever possible. Mitel has already signed up nearly 30 such dealers. The corporation also plans to sell the product indirectly through interconnect telecommunications companies and directly to the large Fortune 500 companies. All these sales efforts are being supported with promotional advertising in professional publications and the prestigious business magazines such as Business Week and Fortune.

Other New Products

The technological know-how generated by the development of the SX-2000 is now also being applied to upgrade the SX-200 range and to design new peripheral products.

An analog version of the SX-200 has been upgraded to accept 480 ports and launched in 1985 as the Generic 1000, or G 1000. New versions of the SX-2000, with enhanced software features and known as the MS-2000 and MS-2001, had also reached the field testing stage by July 1985.

The Superset series are optional telephone sets available to existing and future Mitel PABX customers. Supersets 3 and 4 provide more convenient access to PABX features (such as conference calls) through a liquid crystal display (LCD) screen. The Superset 7 provides similar and added features through a cathode ray tube (CRT) display. These enable the user to monitor the details and costs of long-distance calls, etc. from individual extensions.

These developments (and others still in the R&D phase of the innovation process) enable Mitel to address all segments of the medium/large PABX market up to 4,000 lines, but the small PABX segment is not being ignored. Whilst the SX-2000 was being developed, Mitel also designed the SX-2. This was a single line PABX with up to nine extensions designed for residential and small commercial users. This segment is very much a commodity or consumer marketplace with competitive features which are markedly different from the larger PABX segments. Satisfying it requires a different corporate culture. Therefore, rather than addressing it directly, Mitel set up a subsidiary company, Trillium Telephone Systems to serve it in 1984. Trillium markets its own product lines using TalkTo as a proprietary brand label. The SX-2 is sold as the TalkTo 109 (one line and nine extensions) and other products now being sold include the Talkto 308 (three lines and eight extensions) and TalkTo 616 (six lines and 16 extensions). Trillium's sales approached $15 million in the first year of its operations and sales of $50-70 million are anticipated in 1985/86.

The range of Mitel and Trillium products is summarized in Exhibit IV.

To consolidate the retrenchment process, in November 1985 Mitel announced a restructuring of its worldwide operations from regionally managed business units to a functional organization (see Exhibit II). The purpose of this restructuring is reflected in the words of Anthony Griffiths the corporation's new President and C.E.O.:

> "As business turns increasingly to global strategies and policies, decentralized management no longer meets the demands of multinational companies such as Mitel. This streamlined structure will simplify decision-making for the forseeable future and assist me in expediting the return to profitability."

Six months earlier, in May 1985, Mitel's achievement in building upon its initial successes was recognized with the announcement of BT's controversial $320 million offer to purchase a majority shareholding in the corporation. Although, this 'friendly takeover' bid was opposed on both sides of the Atlantic, on January 27, 1986 the British government announced its approval of the merger subject to certain limitations upon the sales of Mitel products to and through BT in the U.K. market. Both corporations accepted these limitations and the merger was approved by the Canadian government shortly afterwards, thus, opening a new chapter in Mitel's intriguing life story.

Exhibit I

SELECTED FINANCIAL DATA ($ million)

(Source: Corporate Annual Reports)

Table 1

Year	1974	1975	1976	1977	1978
Revenue	.012	.315	1.526	5.407	11.528
Net income	(.04)	.025	.159	.501	1.146

Table 2

Year	1979	1980	1981	1982	1983	1984	1985
Revenue	21.648	43.411	111.212	204.100	255.100	342.600	370.800
Acounts Receivable	6.249	13.1	38.5	64.3	69.7	74.3	106.8
Gross R&D Expenses	2.598	3.473	9.4	24.5	36.6	68.3	59.7
Inventories	5.815	23.4	50.9	99.8	118.3	149.6	134.7
Long-term Debt	2.897	4.351	16.8	32.8	183.7	192.7	209.0
Net Incone	3.096	5.562	14.3	27.9	14.8	(32.4)	(32.1)

EXHIBIT II
(Source: Corporate Records)

MITEL CORPORATION

BOARD MEMBERS/CORPORATE DIRECTORS

Deryk Vander Weyer	Chairman of the Board British Telecom Centre 81 Newgate Street London, UK EclA 7AJ
Anthony F. Griffiths	President and Chief Executive Officer
Christopher Bull	British Telecom Centre 81 Newgate Street London, UK EC1A 7AJ
Dr. Michael C.J. Cowpland	Corel Systems Corp. 1600 Carling Ave. Ottawa, Ontario K1Z 7M4
Albert Gnat	Lang, Michener, Cranston Parquharson & Wright Barristers & Solicitors 1 First Canadian Place Toronto, Ontario M5X 1A2
David A. Golden	Chairman Telesat Canada 333 River Road Ottawa, Ontario K1L 8B9
Mr. David Leakey	British Telecom Centre 81 Newgate Street London, UK EC1A 7AJ
Terence H. Matthews	Mitel Corporation 350 Legget Drive, Kanata, Ontario K2K 1X3
Donald Colin Webster	Helix Investments 2400 401 Bay Street Toronto, Ontario M5H 2Y4

11 March, 1986

EXHIBIT II (continued)

MITEL CORPORATION

OFFICERS

Deryk Vander Weyer	Chairman of the Board
Anthony F. Griffiths	President and Chief Executive Officer
Kent H.E. Plumley	Secretary & General Counsel
William Craigie	Executive Vice President, Research & Development
Duncan A. Campbell	Executive Vice President, Finance
George H. Gilmore Jr.	Executive Vice President
Thomas Mayer	Executive Vice President Operations
Franklin T. Julian	Executive Vice President Marketing and Sales
Dr. Douglas Smeaton	Vice President Semiconductor Division
Harvey Betsalel	Vice President & Treasurer
John Chellingworth	Vice President and Corporate Comptroller
J. Desmond Byrne	Assistant Secretary and Associate General Counsel
William Kiss	Vice President, Quality
Peter Berrie	Vice President, International Sales & Marketing

18 March, 1986

EXHIBIT II (continued)

Business Regions and Divisions

Canadian and International Business Region

* Mitel Corporation
Kanata, Ontario

Burnaby, British Columbia
Edmonton, Alberta
Halifax, Nova Scotia
Mississauga, Ontario
* Renfrew, Ontario
St. Laurent, Quebec
Willowdale, Ontario
Winnipeg, Manitoba
Bayamon, Puerto Rico
* Guadalajara, Mexico
Mexico City, Mexico
Tokyo, Japan
* Tsuen Wan, Hong Kong
* Wellington, New Zealand

United States Business Region

* Mitel, Inc.
Boca Raton, Florida

Atlanta, Georgia
* Bayamon, Puerto Rico
Dallas, Texas
* Deerfield Beach, Florida
Fairfax, Virginia
Irvine, California
Lakewood, Colorado
Oakbrook, Illinois
* Ogdensburg, New York
San Mateo, California
Tarrytown, New York

Europe, Middle East and Africa Business Region

* Mitel Telecom Limited
Severnbridge Estate
Portskewett, Newport,
Gwent, Wales

Slough, England
Birmingham, England
Leeds, England
Amsterdam, The Netherlands
Copenhagen, Denmark
* Steinbach, Federal Republic of Germany
Nicosia, Cyprus
Rome, Italy

Semiconductor Division

* Mitel Corporation
Kanata, Ontario

Bromont, Quebec
Boca Raton, Florida
Dallas, Texas
Haverton, Pennsylvania
Oakbrook, Illinois
San Diego, California
San Jose, California
* Guadalajara, Mexico
* Caldicot, Wales
Copenhagen, Denmark
Milan, Italy
Tsuen Wan, Hong Kong

* Manufacturing location

EXHIBIT III

(Source: Dalhousie University MBA students' paper)

The SX-2000 - TECHNICAL DATA

The PBX system SX-2000 from Mitel is structured as a modular product that can be expanded to the customer's requirements with the addition of line cards. The basic unit of the SX-2000 is packaged in a 'refrigerator size' cabinet. This cabinet can set in the corner of an office. The advantage of the SX-2000 is that it is smaller, uses less power, but has five times the per line data capacity of any of its competitors with a requirement of only 14 square feet, 2.5 kilowatts per 1500 lines, and a maximum data transmission rate of 256 kilobits per second.

The product is based heavily upon Mitel custom circuits for switching, D/A conversion and line interfacing based upon Mitel's ISO-CMOS technology. The custom-designed IC's are the MT 8980 "digital time/space crosspoint switch chip", the MT 8960 filter/coder chip which offers digital/analog and analog/digital conversion plus on chip gain adjustments, the MT 8975 DS1 which provides data rate conversion and protocol interfacing to a T1 carrier for digital trunking, the MT 8970 DLIC that interfaces to a 4-wire line to provide the correct signalling and protocols to handle traffic at 256 kbps, and the MD68SC49 bus monitor that monitors data flow throughout the system as a diagnostic maintenance device.

The main control unit is run by a microprocessor, the Motorola 68000, which uses a 16 bit architecture with 24 bit addressing, and also has both RAM and bubble memories (an INTEL designed product). This unit houses all programs and also the customer data. In the main control section a maximum of 768 ports can be handled. The switch can then be increased in increments of 768 ports per peripheral self pair or 1530 ports per cabinet, up to a single group maximum of 5376 ports. The maximum for a multi-group configuration has not yet been precisely established but it is assumed to be far in excess of 10,000 lines.

The distributed multi-processor architecture is simple but very effective. At the top level, the main control complex draws on a RAM memory with a storage capacity of 3 megawords. The main control complex set up the commands for the message switch which controls the inner working of the SX-2000; it also determines the paths for the circuit switch which handles the PCM voice and data information. The distributed microprocessor controlled architecture provides for intelligence at every level and even into peripheral cards in some instances.

EXHIBIT IV

(Source: 1985 Corporate Annual Report)

PRODUCTS AND STRATEGIES FOR THE LATE 1980s

Despite widely differing global standards, Mitel has been able to make and sell more PABX systems than any other manufacturer and is the largest vendor to the international marketplace with sales to more than 80 countries. We expect the list of countries to grow in fiscal year 1986 in line with our strategic direction.

The bulk of the world's transmission facilities today are analog but over the next five years many of these will be changed to digital. Mitel products are designed to offer full compatibility with both analog and digital networks, through new product introductions and upgrades to existing products.

The Mitel strategy is to provide a worldwide family of technologically compatible PABX systems that network together, offer identical user functions and support the same peripherals. These products will support integrated voice/data communications and allow the user to migrate through the family of products with minimal disruption.

The SX-2000 Integrated Communications System

In the telecommunications industry, the successful launch of a new, large office communications switching system is a significant event. It is by no means a trivial accomplishment. In the case of the SX-2000 **Integrated Communications System** (ICS), we offer a product designed from the voice/data perspective of the mid 1980s. Product designers working in the preceding decade simply did not have today's view of how voice and data might be handled to serve the needs of business communications.

The SX-2000 ICS was designed to provide low-cost, flexible, and comprehensive solutions to the needs of customers in the 1980s and beyond. The successful launch of this product represents the coordinated achievement of many Mitel People with expertise in system architecture, integrated circuit design, software, hardware, manufacturing, marketing, and product support. As a tribute to their vision and hard work, in the first year of product availability, the SX-2000 achieved sales levels and market penetration unmatched in the history of large system introductions.

The system architecture, technology, compatibility with digital communications standards, networking, combined with the worldwide Mitel presence, makes the **SX-2000 Integrated System** particularly attractive to multinational customers. The product has now been developed to handle up to 4000 extensions and planned SX-2000 enhancements have been identified through calendar year 1987 and this work is under way.

The SX-200 PABX
The World's Most Popular Business Telephone System

The SX-200 business telephone system was introduced by Mitel in 1978. This system type accounts for over 30,000 of the more than 85,000 Mitel systems in service around the world. Because the system features are based mainly upon software, Mitel has been able, through a continuing development program, to maintain the SX-200 as a technology leader in the marketplace.

In 1983 the Superset 4 telephone was introduced across the product line together with Generic 217. In 1984, another station instrument, the lower priced Superset 3, went into volume production.

The New Mid-Size Digital PABX
SX-200/Generic 1000

By mid-1985, Mitel will be shipping a new digital switching system, SX-200/Generic 1000 which uses the same digital technology found in the SX-2000. The system's feature complement is based on the most recent SX-200 software release, Generic 217.

The maximum number of ports in the system is increased from 208 to 480 and the digital switching matrix, based on the DX chip, is non-blocking. The digital SX-200 will support up to 128 Superset telephones and is distinguished by a completely redesigned operator console.

Tenanting Opportunities with the New Digital SX-200

In the United States, current regulations permit the resale of telephone services. Profit potential from resale of services has led enterprising developers to begin offering telephone service to building tenants. The new digital SX-200 supports up to 24 separate businesses, making the system an ideal choice in such operations.

The SX-200 PABX
Past and Future

While the digital SX-200 is being emphasized as a new product offering, the package can be applied to any SX-200 currently in service, including the very first system sold in Blair, Nebraska in 1978. This upgrade market represents a second significant opportunity for SX-200 revenue growth. The tradition of backwards compatibility will be maintained in the future with enhancements.

In the first software release, the digital SX-200 provides a rich foundation of features. Further product development is underway in the areas of networking, data handling and applications processing.

Development Continues
on Mitel Small Systems

The Supergeneric software package introduced on the SX-10 and SX-20

PABX systems during fiscal year 1984 has had a favorable impact on sales. The flexibility of the package, its improved hotel/motel features, and networking capability has allowed these products to address new business categories. During fiscal year 1985, the SX-10 was enhanced by expanding the line size from 16 to 32 lines, and by offering an operator's console. The expanded version is now known as the SX-10E. In addition, sales of the SX-20 reached record numbers during fiscal year 1985 and the product continues to be the most versatile performer in the Mitel product family.

Entrepreneur

Fiscal year 1985 marked the successful launch of the **Entrepreneur** system, a compact, four-line, ten-extension business/residential telephone system. The system incorporates special telephone sets that provide simple access to a wide range of business communications features. In the Mitel tradition, the system also offers the benefit of working with lower-cost standard telephone sets, decorator telephone sets, modems and answering machines.

Call-Costing Tools

Dart

Telephone costs are a major business expense. In order to manage these costs it is necessary to identify them. Mitel offers a cost-management tool tailored for small businesses, and a service bureau for large business users across Canada.

The **Dart** (Dialed Activity Reporting Terminal), used with Mitel or other systems in the SX-20 to SX-200 PABX size ranges, provides a variety of detailed summary reports on telephone costs and provides three distinct benefits to its owners.

Dart identifies misuse and abuse of telephone services. Misuse includes unintentional dialing of long-distance calls over a more expensive carrier rather than using a lower-cost resource. Abuse includes the use of business telephones for unauthorized personal long-distance calling. Misuse and abuse can account for as much as 30 percent of a monthly telephone bill.

Dart enables a business to analyze communications resources such as INWATS and OUTWATS lines and to optimize usage of such facilities. When such services are under-utilized they cease to be cost-effective. An over-worked service frustrates both employees and outside callers.

A Unique On-Line Update Service

There are more than 3,000 telephone companies in North America and a number of government telephone authorities worldwide. This large number of players insures constant change in telephone service rates. Mitel maintains accurate rate tables for Dart owners through the optional Quarterly Update Service provided directly through on-line modem connections.

CMS for the Canadian Fortune 500

Mitel Communications Management Services (CMS) provides comprehensive call-costing information to users of large Mitel PABX systems and other large systems across Canada. CMS was founded in 1977 and is Canada's most experienced call-costing group.

CMS reports allow telephone costs to be allocated to departments within a business and/or accurately charged to business clients. The reports also provide an evaluation tool that lets telecom managers monitor communications requirements to ensure that the best least-cost facilities are available to the users.

Transparent Data Collection

Call record data is collected on-line. Reports are prepared and verified monthly. The CMS rate tables are updated on a continuing basis to assure the most accurate call-costing for CMS customers. Mitel Communications Management Services offers worry-free call accounting and reporting for management.

Kontact Workstation Gain Approvals/Capabilities

A new 1200 baud auto-select internal modem was developed for **Kontact** during fiscal year 1985 and a records management capability called **ExecuBase** was added to the **Kontact** software library.

The **Kontact** multi-function, multi-tasking workstation was approved for connection to the public voice/data networks in Australia by Telecom Australia, and similar approval was granted by the British Department of Trade and Industry. In the United Kingdom, **Kontact** provides access to Teletex data bases. Teletex is the standard for Videotext services in Britain.

Mitel Semiconductor

Mitel Semiconductor had a year of record revenues in fiscal 1985 with a sales growth of over DTMF or Dual Tone Multi-Frequency signaling is currently used throughout the private, alternate common carrier, and public switched telephone networks worldwide. Today's products range from filters and decoders to completely integrated 50 percent. The Division has established a broad customer base particularly within the voice communications industry.

DTMF Components

Mitel was originally founded as a supplier of DTMF products. DTMF or Dual Tone Multi-Frequency signaling is currently used throughout the private, alternate common carrier, and public switched telephone networks worldwide. Today's products range from filters and decoders to completely integrated single chip receivers. These components made a major contribution to the past year's sales growth. The strong position in this market will be further enhanced by the introduction in fiscal 1986 of a completely integrated DTMF transceiver.

ST-BUS Components

Throughout the 1980s and 1990s, growth in digital telecommunications has been forecasted by industry analysts to be explosive. While Mitel Semiconductor has already achieved a significant role in the telecommunications component market, the introduction of a comprehensive and growing family of digital communications components has positioned the Company to maximize opportunities offered by the growth in this market.

The ST-BUS family of components is designed to provide a wide variety of functions for the handling, manipulation and transmission of voice, data, and control information. All components in the family are mutually compatible by using ST-BUS interfaces. The ST-BUS is a serial bus interface, developed by Mitel to simplify and enhance the design of a wide range of digital communications systems based on a common set of components. The ST-BUS family also provides a solid base of components from which to address the newly emerging international standard Integrated Services Digital Network (ISDN) market.

Components for ISDN

A major emphasis in fiscal 1986 will be towards components for ISDN systems. Today there are few digital transmission facilities installed, but it has been estimated that as early as 1990, 50 million lines will be in service working to ISDN standards.

Mitel has already developed an integrated circuit addressing the needs of ISDN. This device, the MT8972, is the first commercially available integrated circuit to address the ISDN 'U' interface, which provides digital transmission service from the central office equipment to the customer's premises.

Trillium Telephone Systems

The establishment of Trillium Telephone Systems Inc. in fiscal year 1984 allows Mitel to Address a worldwide market for small business communications systems worth more than $1 billion annually. The market includes 2.5 million aging electro-mechanical key systems in the United States alone, most of which will be replaced with electronic key systems over the next five years. The replacement market is estimated to be worth approximately $4 billion.

The key system market is well established, and is by tradition quite a different market segment from the PABX market. Trillium opens a new and profitable direction for the Company in the low-end market segment.

An Eventful First Year

In its first full year of operation, 150 Trillium Authorized Dealers were appointed. In Canada, a distribution agreement was signed with AGT, while in the United States agreements were reached with Centel, a large Chicago-based dealer, and also GTE. In the fiscal year 1986, Trillium will take new products to the retail marketplace, taking advantage of a new distribution trend for small telephone systems.

The TalkTo 109

The first Trillium product, the **TalkTo 109** , is a small business/home communications system with a single outside line. It supports up to five telephone sets or special telephone sets and as many as four monitor units. With an optional plug-in module and appropriate interfaces, any telephone in the system can be used to control home appliances. The product is meeting with early success, particularly in Sweden where the Swedish Telecommunications Administration took delivery of approximately 9,000 systems during fiscal year 1985. An additional 2,500 systems wre ordered for delivery during calendar year 1986 as part of a three-year agreement.

New Products

New Trillium products include the TalkTo 616, 308, and 208 telephone systems, and the TalkTo 1000 special telephone set.

TalkTo 616

The TalkTo 616 provides telephone service and advanced features for up to six outside lines and as many as sixteen telephone extensions. Competitively priced and easy to use, the TalkTo 616 is a high-reliability product, offering advanced features including speed dialing, add-on conference, direct station select and paging.

TalkTo 308

The TalkTo 308 is designed for smaller businesses and larger homes. It supports up to three telephone lines and as many as eight telephone extensions. Attractive and easy to use, the TalkTo 308 is a highly featured, low-cost alternative to older illuminated-button key systems, such as the 1A2, which are being rapidly phased out.

TalkTo 208

The multi-featured TalkTo 208 key system can accommodate eight TalkTo 208 telephone sets and two outside lines. In a residential environment the product is able to provide door answering, room monitoring, and energy management in addition to providing efficient communications. The TalkTo 208 offers feature enhancements to the total system when used in a business setting with a PABX or CENTREX.

The TalkTo 1000

A new special telephone set, the TalkTo 1000, was announced by Trillium near the ned of fiscal year 1985. A liquid crystal display is used to show both messages and user prompts, giving the set excellent communications capabilities while making it extremely easy to use. The TalkTo 1000 single line telephone is designed to work with all Mitel PABX systems, PABXs from most other manufacturers, and with CENTREX systems. The set is currently undergoing field trials.

During fiscal year 1986, Mitel is expecting significant growth from the new Trillium product line and from the small telephone system business.

CAE ELECTRONICS LTD.

The United Airlines afternoon flight was shortly due to leave Hollywood International Airport, Fort Lauderdale, Florida bound for Norfolk International in Virginia. In preparation for take-off, Captain Scott Fader was going through normal cockpit checks. Once these were concluded the engines were started. This was followed by the bump of a tug hooking to the nosewheel towbar. Shortly afterwards the Boeing 727 began its movement backwards from the terminal gate, the passenger boarding bridge slipping past on the left-hand side of the cockpit. As Scott taxied toward the runway, he noticed a business jet taking off to his right. The bumps of the taxiway were apparent as first the nose wheel and then the main gear crossed over its tar-filled cracks.

After a short wait, the control tower gave clearance for take-off. Power was increased and the level of engine and air-conditioning noise grew appreciably. As the plane accelerated toward take-off speed, the cockpit swayed from side to side. The noise from the tar strips grew closer together but finally disappeared as the 727 rose into the air. The plane climbed quickly and experienced a period of turbulence which juddered the cockpit instruments in their mounts and tossed Scott around in his seat.

This case was prepared by Professors Philip Rosson and Michael Martin of Dalhousie University as a basis for class discussion rather than to illustrate effective or ineffective handling of an administrative situation. The authors gratefully acknowledges the financial support of the Federal Department of Regional Industrial Expansion, Office of Industrial Innovation in the development of the case.

Once the 727 climbed out of the clouds, the turbulence ended, and with normal cruising altitude achieved a period of relative calm was enjoyed.

Later on, however, the calm was ended. Scott could see thunderstorm and cumulus cloud buildups in the Norfolk area. The thunderstorms were forecast to coincide with the flight's touchdown time at International. Scott mulled over in his mind whether to divert to an alternate airport, or, if he continued, what kind of turbulence and wind shear he should expect to encounter. After due consideration he elected to continue to Norfolk.

As the plane descended the turbulence was so intense it rattled Scott's teeth. The turbulence continued as the 727 came down through the cloud deck on an instrument landing system approach. Then green and brown patches of the surrounding countryside were visible as the clouds were left behind, but these faded as the rain shower intensified. The runway strobe light came into view two miles out from the active runway, and shortly afterwards, the white runway lights appeared. Just before landing, reflections of the runway border lights told Scott to expect water on the runway and, as a result, reduced braking effectiveness after touchdown.

Scott made a near-perfect landing, rapidly deploying the spoilers and thrust reversers. The plane's ground roll was longer than normal because of the wet pavement, but soon the United flight was ready to disembark at the terminal gate. Had Scott been piloting a planeload of passenegers, a collective sigh of relief would have been breathed - for landing conditions had been tricky enough to unsettle even the hardiest air-traveller. As it was, Scott was sitting in a 727 flight simulator in United's Denver, Colorado training complex. Whilst he had scored 'points' for the landing, it was with an instructor and not with 130 passengers!

Flight Crew Training and Simulators

Like the fictitious Captain Fader, most flight crews are being trained on simulators which very realistically mirror 'real' flying. There are two main reasons for this trend. First, it is considerably cheaper to train on the gound than it is in the air. For example, the either direct or opportunity (in foregone passenger revenue) costs of operating a Boeing 747 is thousands of dollars an hour, whereas a simulator costs between $400-600 an hour (amortized over 12 years and including buildings, etc.). The savings can be expressed another way. Western Airlines of Los Angeles estimates the cost of a captain upgrade from first officer for a Boeing 727 to be $4,600 when flight training is used versus $1,400 on a simulator.

Second, the quality of training achieved is better on the simulator. Some situations cannot be set up on a real airplane. For example, it is not possible to cut off engines to gauge pilot response. Nor it is possible to test what the pilot would do should a fire start in a cargo hold, or anywhere else in the aircraft. Each of these situations can, however, be simulated, as well as many more. In fact, the training instructor can establish almost any sequence of conditions or malfunctions for the trainee.

So as well as being financially beneficial, simulators - in the view of airline flight trainers - produce better pilots, because they make more comprehensive training programmes possible.

In response to the training requirements of airlines, as well as the increased level of sophistication in simulation technology, the U.S. Federal Aviation Administration (FAA) published its Advanced Simulation Plan in June 1980. This specifies five levels of certification of flight simulators: non-visual, visual, Phase I, II, and III. Phase III simulators are the most sophisticated. Each level allows progressively more training to be transferred from the aircraft to the simulator. Non-visual and visual simulators allow credits to be given for certain ground, take-off and flight manoeuvres, whereas the Phase I, II, and III simulators allow various categories of training to be done entirely in the simulator.

The training allowed under each Phase level is summarized as follows:

- Phase I: (i) recency of experience, (ii) night take-offs and landings, (iii) landing proficiency checks,
- Phase II: Phase I plus (i) transition training between aeroplanes in the same group for all pilots, (ii) upgrade to pilot-in- command from first officer,
- Phase III: Phase II plus initial training for new pilots.

With the high cost of operating aircraft, it is in the interest of most airlines to obtain the highest certification consistent with their training needs. Currently, only one airline - United - has a Phase III certified simulator (for a 727). Many other airlines are not concerned with training new pilots and so find their biggest return comes from Phase II certification. This is easier to obtain and maintain (the FAA makes quarterly checks) and provides most of the training credits required.

Outside the U.S., other nations have their own bodies which regulate the training of air crews. Canada has its Department of

Transportation. In Britain, the appropriate body is the Civil Aviation Authority, whilst in Australia it is the Department of Aviation that has jurisdiction. Each body has a somewhat different set of rules and standards regarding simulator training, but in essence they approach the matter in much the same way as the FAA.

The Commercial Flight Simulator Market

The years 1979 and 1980 were significant ones for simulator manufacturers around the world. A number of factors came together to make this a time when numerous simulators were ordered. The escalating price of fuel and diminishing passenger traffic put a tremendous pressure on airlines to seek-out ways of using their aircraft more efficiently. One way to achieve savings is for aircraft not to be removed from revenue generating operations for air crew training. In other words, it pays to use of simulators for more of the training load.

Another response by the airlines to the high cost of fuel was the purchase of new aircraft. The new breed of aircraft like the Boeing 757 and 767, and the McDonnell Douglas DC-9 Super 80, were much more fuel efficient than those currently in service, and as these planes were purchased, so the need for new simulators began to be felt.

As well as the demand for new simulators, upgrading of existing simulators provided work for manufacturers. With the new airline operating conditions, the capital cost of upgrading from Phase I to II made more and more sense. The net result of these various factors shows up in Exhibit I. Since there is about a two year lag between placing an order for a simulator and receiving it, the peak years of 1981 and 1982 reflect orders placed in 1979 and 1980 respectively.

Since 1982, demand has declined markedly. The main reason for this is the financial plight of most airlines. Revenues are down and costs up. Revenues are down because of lower traffic levels and lower (discounted) fares. Most costs continue to grow although there has been some respite as far as fuel cost increases are concerned. Under such severe financial pressure many airlines are simply unable to invest in further simulators or in upgrades. A second reason for the decline in simulator demand is that many airlines now have their full complement of simulators for the new planes they have purchased.

In general terms, it was estimated that once an airline had about 20 planes of a particular type, the purchase of a simulator could be justified. Below this level it was more sensible for the airline to rent time on some other company's simulator. The ratio of 20:1 varied, however. A look at deliveries of planes and simulators around the world yielded some interesting comparisons. For example, by 1983 about 1830 727s had been delivered in total and 72 simulators for 727s, giving a ratio of about 25:1. A similar ratio existed for the DC-9 Super 80, whereas that for the 747 was 12:1.

The way these different aircraft were used partly explains the discrepancy. Both 727 and DC-9 Super 80s are used on short-haul flights whereas the 747 is a truly long-haul plane. Aircrews can be used much more intensively on the former than the latter. For example, the same flight crew might fly a 727 from New York to Boston in the morning and bring another back later in the day. In contrast, a 747 flight from London, England to Los Angeles then over the Pacific involves three legs, with a new crew for each, and often comparatively lengthy layovers for crews between flights. Airlines with long-haul routes tend then, to require a larger complement of air crews than those concentrating on short-haul, and as a result also have greater training needs.

With these sorts of considerations in mind, simulator manufacturers were able to forecast demand for their equipment. They knew precisely what aircraft each airline had and their close contacts with both airlines and planemakers kept them informed about possible fleet additions. In the summer of 1983 the only plane that was selling at all was the DC-9 Super 80. This was a derivative of an aircraft that had been around for 20 years or more. McDonnell Douglas had taken their slow-selling DC-9, re-engined it with super efficient new units, added the latest in flight instruments, offered some very compelling financial arrangements and as a result were doing very well with their Super 80. The plane was proving to be very cost-efficient; the 150 seat, medium-range, fuel efficient, competitively priced features were just what many airlines were looking for in a period of overcapacity and intense rivalry for traffic.

Despite the success of the DC-9 Super 80, simulator manufacturers regarded any major upturn in orders as being unlikely. Some improvement was anticipated but only to a level of 10-15 units annually.

Three main commercial flight simulator manufacturers competed for this business in 1983: Link, Rediffusion and CAE. The largest producer of flight simulators in the world is the Link Division of the famous Singer Company. As well as being the leading maker of sewing machines, Singer manufactures a diversified range of products for consumer and government markets. Link - with facilities in the U.S. and U.K. - represents part of Singer's aerospace and marine systems interests. Rediffusion Simulation Ltd. is also part of a substantial business operation. This U.K. company is a subsidiary of a company with business, consumer and capital electronics arms, as well as others. The company is Rediffusion Ltd. The third major competitor is CAE Electronics Ltd. (CAE) of Canada whose activities are described later.

Several other competitors feature less prominently than those above. Thompson CSF is a French company resulting from the nationalisation of part of ITT's (the U.S.-based multinational) interests in that country. GMI and Reflectone Inc. are U.S. simulator manufacturers.

Historical and Corporate Background of CAE Electronics Ltd.

The origins of CAE go back to 1947 when it was incorporated as Canadian Aviation Electronics Ltd. In the early days it principally engaged in the repair and overhaul of electronic and electromechanical equipment and services. In the 1950s it began to produce flight, radar and weapons simulators for Canadian defense requirements. The technical skills and facilities developed during the production of some 80 military flight simulators for 12 western nations led CAE into the commercial simulator field.

In 1962, CAE began an acquisition and diversification programme. This helped to reduce the relative importance of defense-oriented business from 90 percent of total sales in 1962 to about 20 percent in 1982. In 1963, the company changed its name to CAE Industries Ltd. to reflect its new, broader set of business operations. The subsidiary divisions in 1983 - CAE Electronics Ltd. is the major one - are shown in Exhibit II.

Corporate headquarters is located in Toronto, Ontario, where four senior officers formulate policy and provide guidance to the subsidiaries as required. Management responsibility is delegated to subsidiary management to the greatest degree practicable, with headquarters acting in a coordinating capacity. Corporation sales in fiscal 1983 were $269.8 million with Electronics and Aviation accounting for $147.1 million or 54.5 percent. Business segment revenues and income for fiscal 1982 and 1983 are set out in Exhibit III. Finally, an historical summary of the company's financial performance is found in Exhibit IV. In 1983, the corporation employed about 3,650 persons across Canada plus others in its West German subsidiary, which services CAE-built simulators located in Western Europe. All others are serviced from Montreal.

CAE Electronics Ltd.

CAE is located in a 30,000 square meter integrated engineering and manufacturing complex on the fringes of Montreal's Dorval Airport. The complex encompasses design, engineering and test facilities, machine shop, welding, plating and painting shops, as well as in-house facilities for making printed circuit boards. CAE also has its own clean room laboratories for the mechanical and electrical calibrations of equipment which must directly conform to Canadian government standards. With some of the company's products being manufactured to MIL-spec* requirements, a sophisticated quality assurance programme is in place. The company employs about 1700 people, of whom about one-third are highly qualified engineers

The company is involved in a number of product/markets:

Flight simulators. Both military and commercial flight simulators are manufactured for fixed wing aircraft and helicopters. In the commercial sector, simulators had been produced for all of the jet aircraft types made by Airbus (a consortia of European governments), Boeing, Lockheed and McDonnell Douglas. Exterior and cockpit views of a CAE simulator are shown in Exhibits V and VI respectively.

A wide range of simulators has also been supplied to different countries for various types of military aircraft, including tactical jet flighters, jet trainers, antisubmarine patrol aircraft and transports. As in the commercial sector, each simulator comprises a flight compartment with instructor's station, a motion system on which the flight compartment is mounted, a computer system and a visual system.

CAE has produced simulators for Agusta, Bell, Boeing-Vertol, Sikorsky and Westland helicopters. The simulation requirements for helicopter pilot training differ considerably from fixed-wing aircraft, particularly in the need for motion cues that accurately

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* Military specifications

reflect rotor vibration and the demand for low level visual system effects in hover and landing manoeuvres.

Avionics. CAE is a world leader in the development and manufacturer of two systems used by defense forces in aircraft employed to 'hunt' submarines. These are the Magnetic Anomoly Detector (MAD) and the Fully Automated Compensation Systems (FACS). The U.S. Military has been a notable customer with around 1,000 FACS for its P3 and S3 patrol aircraft. At the 1983 Paris Air Show, CAE generated great interest with a substantially improved MAD system and hoped to capitalize on this opportunity in the next few years. The new equipment had been very successfully tested by the U.S. Navy and the company was expecting an evaluation order for a few units as a prelude to possible procurement.

Nuclear Power. CAE's expertise in flight simulators took them into training simulators for the nuclear power industry. The simulator trains operators to develop experience in responding to all normal, abnormal and emergency conditions and to learn required operating procedures and techniques. Four orders had been received for simulators from Ontario Hydro* (two had been delivered), and one more order was expected. Although this business provided useful revenue in the short-term, the long term future of the nuclear power industry was uncertain.

In addition to producing simulators for the nuclear industry, CAE manufactures systems for monitoring and controlling all major reactor and power plant functions. Once again, however, this market was not felt to be the most promising in the near future.

*The public corporation which generates and distributes electricity to users in Ontario. Hydro-Quebec (see next page) provides the same service in Quebec.

Electrical Power, Oil and Gas. As well as the supervisory systems for nuclear power stations, CAE manufactures similar systems to monitor and control complex electrical power transmission networks and oil and gas pipelines. The company's work with Hydro-Quebec on the massive James Bay energy project had led to the first off-shore order for a control system in Venezuela. Hopes were high that further sales could be made around the world although competition from industry giants such as IBM, Hitachi and TRW was strong. Fortunately, Ontario Hydro and Hydro-Quebec were very highly regarded by other utilities and were involved in overseas consulting in certain areas. Because of their association with these two organizations, CAE stood to benefit from these activities.

Air Traffic Control. Company skills in aviation electronics and computer technology led the company into the air traffic control area. A $20 million contract to design and manufacture the Joint En Route and Terminal System (JETS) was awarded in late 1973. The system was installed at the Toronto and Montreal terminal centres and seven en route centres for the Department of Transport between 1980 and 1982.

Space. CAE is part of a Canadian consortium responsible for developing and manufacturing the Remote Manipulator Arm System for NASA's Space Shuttle. The Shuttle is a unique, reusable cargo-carrying combination spacecraft-aircraft that can transport weather and communications satellites into space or serve as an earth-orbiting laboratory. An articulated manipulator arm, with a 14-meter reach releases satellites into orbit, or retrieves them for repair in space or return to earth. CAE designed and manufactured the display and control panel plus the rotational hand controls that operate the manipulator itself.

The manipulator system concept is felt to offer exciting potential for future application in other hostile environments, such as the arctic or ocean floor where resource extraction or scientific studies must be carried out.

Because of the nature of CAE's business - the design and manufacture of custom-made, expensive capital equipment to satisfy particular requirements - orders are 'lumpy.' As a result, the importance of the various product/markets varies from year to year. In fiscal 1980 for example, commercial flight simulators and nuclear power simulators were equal in importance, whereas the shrinking of commercial flight simulator business in 1982 left nuclear power simulators as the largest revenue earners. Even though the flight simulator business fluctuated from year to year, it was a very important part of company operations; over the 1973-1983 period it had accounted for about 60 percent of total CAE sales.

CAE and Commercial Flight Simulators

CAE's first true flight simulator was built for the RCAF, representing a Canadair Argus maritime-patrol aircraft. Then in the early 1960s, 32 F-104 Starfighter trainer simulators were produced - 6 for the RCAF and the remainder for the NATO air forces of Germany, the Netherlands, Belguim, Italy, Norway, Denmark, Greece and Turkey. These analogue computer-based simulators are still in service.

From these military simulator beginnings, CAE moved into the commercial field, building its first two digital computer-based simulators (DC-9s for Swissair and KLM) in the mid-1960s. Since that time, it was produced about 60 units for airlines and manufacturers in some 20 countries. When the price of a simulator is considered - $7-10 million at 1983 prices - it is obvious that these have brought sizeable revenues for CAE over the years.

Numerous innovations in simulation technology have been introduced by the Montreal producer. These include, a hydrostatic six-degrees of freedom motion system, the use of general purpose computers, and cathode ray tube based instructor's facilities. One force behind these developments is the customer - CAE reckons to have had a particularly demanding set of clients including Swissair, KLM, British Airways, United and the West German Air Force and Navy.

By 1983, there were no gross technical differences between the simulators offered by the leading manufacturers, so that marketing activities assumed greater importance than in the past. This was even more the case given the shrinking demand situation.

Winning Simulator Orders

As might be expected with a capital item of this kind, simulator orders are put out to competitive bidding. The bid process is initiated when the airline or manufacturer sends a Request for Proposal (RFP) to simulator manufacturers. This should come as no surprise to producers, for the airline community is a small one and its members sufficiently mobile to make for fairly free information flows. The way in which CAE prepares its bids is shown in Exhibit VII.

The Bid Process. The steps involved from receipt of RFP to CAE's winning an order are as follows:

1. RFP states the type of aircraft and the number of simulators desired, as well as general technical requirements and delivery schedule.

2. At CAE, the Sales/Marketing group handles bid preparation.

3. The first decision taken by management is whether to respond to the RFP or not. These days the company bids on almost all airline simulators.

4. If a decision is taken to bid on the RFP, an estimate order is issued by Sales Administration requesting all participating line departments to review the RFP and prepare estimates based on the technical requirements specified.

5. Technical information about the plane to be simulated as well as details of simulator requirements, enables Engineering to: i) prepare a work statement, and (ii) write a technical proposal.

6. The work statement is written to advise Estimating of the hardware content of the simulator, such as the computer and peripherals, motion system etc., so that costs can be established.

7. The technical proposal is written by Engineering and should be a paragraph by paragraph response to the customers' RFP. This proposal describes the extent of simulation of the aircraft systems and gives tolerances on all the computed parameters. Deviations from the RFP are sometimes suggested if these seem advantageous. Where the customer's request cannot be complied with a waiver is requested giving reasons for this.

8. The engineering estimate is a breakdown of hours required for: i) Systems Engineering, ii) Equipment Engineering, iii) Mechanical Engineering, iv) Test and Calibration, v) Mechanical and Electrical Drafting, and vi) Computer Services.

9. Supporting services required may include: i) type of shipment of simulator (air, sea or land), ii) training of customer personnel, iii) documents, iv) spares, v) field tools and test equipment, vi) field service representative and vii) on-site maintenance. Support service requirements are established through the proposal development process.

10. The estimating department prepares an overall cost estimate for the simulator by using the work statement prepared by Engineering and the individual line department estimates, including materials and manufacturing labour, and taking into account overhead rates and general and administrative costs. The cost estimate is reviewed by Sales and Management to establish a selling price to the customer.

11. A master schedule is produced showing the phases involved in simulator manufacture.

12. A price and delivery proposal is submitted to the customer accompanying the schedule and technical proposal. It covers the terms and conditions, federal taxes, payment schedules, or financing charges. It might also contain a draft contract. The whole package is now submitted to the customer for review and appraisal.

13. When the various bids have been submitted, some or all manufacturers are involved in a 'customer evaluation.' This is a period of review, technical discussion, specification and price modification. The alternatives and options submitted are discussed with the customer. The competing tenders are weeded-out as the bid process comes to its conclusion.

14. When one manufacturer has been selected, the next stage in the proceedings is one of contract negotiation. The draft contract is written and re-written until it satisfies both parties.

15. Finally the simulator order is received, setting off a new round of activities.

About three to four weeks were required for CAE to bid on a particular RFP and the shortest RFP to order period was about six months. The cost of preparing a bid varied anywhere from $15 -- 100,000 for commercial flight simulators depending on how well the company knew the customer and its familiarity with the type of simulator required. Military simulator bids cost up to $500,000 to prepare.

Buying Behaviour. Airlines differed in their buying behaviour. Some tended to buy their simulators from one source whereas others moved their business around. For example, all five of KLM's simulators were CAE ones (Exhibit VIII), while Link had a monopoly at Delta Air Lines (9 simulators - see Exhibit IX), and Rediffusion had secured six of the seven South African Airways simulators. These airlines obviously saw merit in sourcing from a single manufacturer. The chief benefit of this approach is the close relationship that develops between the two companies and economies that come from standardization of supply.

Other airlines obviously do not consider there to be sufficient merit in single-sourcing. For instance, British Airways has 15 simulators (Rediffusion - 8, CAE - 4, Link - 3); Trans World Airlines has 11 (Link - 7, CAE - 2, Rediffusion - 2).

Pricing is clearly important but so too are technical standards. Perhaps all that can be said about buying behaviour is that each customer has his own 'hobby-horse' which has to be satisfied. But each sale really has to be treated differently because the ground-rules can and do change. For one thing airlines personnel are not static - they are promoted, shuffled sideways or leave; thus the composition of buying teams can and does vary. As well, the competitive situation fluctuates. Suppliers are much more 'hungry' for orders at some times and, as a result, are willing to give-up more of their profit margin. Exchange rate movements often favour a supplier located in one country over others. Finally, suppliers are affected by the competitiveness of export financing arrangements available in their country.

After the simulator bids were in, a round of tough bargaining frequently took place. Sometimes the airline called all bidders to the negotiatons, locating them in adjacent rooms. An 'auction sale' atmosphere sometimes prevailed, customer personnel doing the rounds in an effort to get the very best deal possible. On other occasions, however, prior decisions limited the number of suppliers to a 'short-list,' from which one was selected.

<u>CAE and Phase III Certification</u>. Although any of the manufacturers could supply good training equipment, their simulators were different from one another. One point that set CAE apart from the others was the fact that they alone had achieved Phase III certification.

United Airlines was anxious to achieve Phase III and in 1979 awarded CAE the contract to produce the 727 simulator in question. CAE tackled the simulation developments while, since CAE does not produce a visual of its own, Rediffusion (CAE's competitor) worked on the visual requirements. United specialists assisted in many ways and played a major role in coordination.

The Phase III project had been a particularly demanding one for CAE. It took a lot of resources to bring the project to fruition, at a time when the normal order book was full and plant expansion was taking place. However, the commitment was made and a year later, after its certification, no other simulator had achieved Phase III status. CAE was talking about a second Phase III simulator - this time for a 747 with a European customer.

Their Phase III work gave CAE - in their executives' opinion - a decided technological edge over the competition. This expertise angle was one they hoped would provide considerable marketing help in the future.

<u>Competitive Strategy and Prices</u>. In the last few years, competition in the simulator market appeared to have slackened. As demand declined, so too had the number of major rivals. Rediffision is now CAE's main opponent. Link appears to be concentrating more and more on military simulators as does Thomson in France. GMI is reputed

to be in financial difficulties, but Reflectone is new to the commercial simulator market, having only recently broadened its military interests.

Although Link and Thomson are mostly involved with the military market - where profits are claimed to be higher - both companies will do airline work. CAE executives believed that these producers would accept work from their 'traditional' customers, but not seek out new commercial business.

In 1983, a simulator cost between U.S. $7 - 10 million depending upon the level of visual system installed. The following breakdown provides an illustration of costs for a simulator at the upper end of this range:

	U.S. $ Million
Simulation system & equipment	4
Visual system & equipment	3
Aircraft parts & data	2
Margin	0.5
Total	U.S. $9.5 million

All simulator manufacturers purchased plane parts and instruments from the aircraft makers to ensure that training cockpits were authentic. In addition, flight data were bought from the same source. This was essential for modelling the aircraft's flight in computer terms. Thus, all simulator producers incurred these costs. The only variation in costs was a consequence of exchange rate movements. Mostly these purchases were made in the U.S., so, when the British pound was weaker than the Canadian dollar against the U.S. dollar, it cost Rediffusion relatively more than CAE to buy the parts and data.

Then again, Rediffusion had more pricing latitude than CAE in the area of visuals. CAE had followed a policy of not producing visuals. Rather than tying the customer to a proprietary visual system, the company believed it better to give the customer a choice of system. In contrast, Rediffusion produced its own visual system. This meant that Rediffusion had some flexibility in this cost area, while CAE did not. Link also had a visuals capability.

Sales organization. Five senior marketing representatives were responsible for selling CAE simulators world-wide (see Exhibit X). From time to time, senior company officers were also involved. Seperate reps covered the military market as the selling process was substantially different than that with airlines. More extensive use of overseas agents was made in the military market and the sales cycle was usually much longer too.

CAE's representatives were not organized on a regional basis although some thought had been given to this possibility. Rather, each person dealt with a wide range of customers, even though these might be scattered across several continents. This system had worked well for the company, since familiarity with and understanding of the customer was judged to be more significant than efficiency of travel plans. The representatives spent a good portion of time each year away from Montreal, either pushing a sale through (negotiations could take as long as six weeks), or learning about and preparing for future sales. They were paid a straight salary, and were well-qualified technically, holding engineering degrees. In fact, most of the representatives were long-standing CAE employees, starting out in technical positions before moving into sales.

R&D/Engineering (R&D/E)

Exhibit XI indicates both the organization and planning of R&D/E which are closely-linked but separate functions. Strategic R&D planning is performed by the R&D Review Committee which is chaired by the Director of R&D (Dr. Murdoch McKinnon) and includes the President, Vice-Presidents and engineering directors. Given its diversified project and product interests, based upon its real-time processing capabilities, the company's R&D interests are equally all-embracing. It must therefore focus its R&D efforts towards satisfying anticipated future market needs which require these capabilities, constrained by the resources available. The purpose of the Committee is to provide and maintain their focus. It meets monthly or as required to establish policy and R&D direction, review new project proposals, the progress of existing ones, and deal with any unresolved crises which may have arisen. Tactical management is handled by the R&D Steering Committee (also chaired by the Director of R&D) to whom the overall R&D co-ordinator reports. He is supported by co-ordinators in each of the four Engineering Divisions who provide the formal link with R&D. Collectively, the five co-ordinators are responsible for day-to-day administration of R&D projects.

Current annual R&D spending is about $30 million and can be divided into three categories (with approximate percentages of the total in brackets):

(i) Internally financed R&D (13%) - This is non-sponsored work which is directed towards some medium or longer-term anticipated market need. For example, significant efforts ($250,000 to date) have been in development work on hand-controllers for space applications and have involved interaction with NASA.

(ii) Funded or contract R&D supporting specific projects (15%) - This work is primarilly supported by government agencies such as the National Research Council (NRC) and National Science and Engineering Research Council (NSERC). For example, about $1 million has been funded under first Programme for Industry/Laboratory Projects (PILP) and then Industrial Research Assistance Program (IRAP) for the computer based training programme (see later). Joint funded work is also undertaken with universities supported by the Department of Regional Industrial Expansion (DRIE) and strategic grant programmes. Direct government support for staff is also provided through post-doctoral fellowships, industrial graduate fellowships and summer studentships. Close links with universities are maintained both by these means and by part-time teaching and graduate student supervision undertaken by company R&D/E staff.

(iii) Individual engineering projects (72%) - Since almost all of the company's "products" are "one-offs", each involves considerable development work. Therefore much R&D is directly funded from individual engineering projects and performed in the engineering divisions tailored to specific project needs and goals.

This last consideration means that most R&D is actually development work on individual projects peformed in Engineering. This arrangement offers other advantages:

a) It ensures that engineering project teams have access to R&D expertise as required.

b) It ensures that R&D staff are attuned to project development needs so do not become insulated in an "ivory tower" environment.

c) R&D can act as a "buffer" to retain good people during troughs in Engineering work-loads. This means that internal R&D funding increases or decreases partially to compensate for decreases or increases in externally supported project engineering.

R&D/E currently employs about 600 professional staff with qualifications ranging from bachelors to doctoral degrees. Most have engineering or computer science degrees and many work on programming and software development. This number fluctuates dependent upon project needs. For example, over 200 graduates were hired in 1984 to implement a major expansion of R&D/E efforts. Given its large demand for qualified professionals and the price competitiveness of its business, the company is forced to pay average rather than top market rates for recently qualified engineers and computer scientists. The fact, coupled with the overall shortage of such in Canada, means that not all its new entrants are Canadian citizens or landed immigrants. Some are people who have completed their university educations in Canada whilst others are recruited from abroad (notably the UK). All recruitees recognize that employment with CAE provides invaluable work experience (particular in software and engineering) and turnover is below the industry-wide average for such professionals.

Gabriel Weintraub, until recently Director of Engineering and now Director of Support Programs, attributes this relatively low turnover to the leadership style of the company. All projects require a significant degree of challenging novel problem-solving, so offer scope for individual creativity. An individual is given early responsibility, freedom and scope to develop his or her own ideas within the boundaries of the budgetted costs (see later) and objectives of each project, in an environment of almost exclusively technical professionals. Most engineering projects require interchanges with customers in the latters' organizations throughout the world, so individuals enjoy early opportunities for extensive travel. Remuneration and promotion is based strictly on merit and individual team members may be paid more than their bosses, the project team-leaders. Group leaders regularly evaluate the performances of all those reporting to them on a five-point scale to maintain the meritocratic culture.

Twelve experienced personnel are permanently dedicated to R&D, whilst 34-40 work in R&D (as against Engineering) at any one time, as and when the need arises. Categories (i) and (ii) R&D above involve substantial interaction with university and government R&D activities and is mainly attuned to long-term (say five years upwards) market opportunities. On the other hand, category (iii) work is focussed on satisfying the requirements of existing contracts and is therefore mainly attuned to short-term needs (say up to three years ahead). This means that there is a danger that the company will miss-out on medium-term market opportunities (say three to five years in the future) because no one is reponsible for scanning this "middle-ground". To avoid this danger CAE has a position called Manager of Business Development who is formally located outside R&D/E and reports to the VP of Sales and Technical Development.

Mike Rowlands, who holds this position, is an electronics engineer with about twenty years experience in engineering and marketing in the aerospace industry. He works as a "one-man band" with no support staff because, as he states, none is needed. His roving commission is to monitor activities on a global basis to identify new opportunities for CAE's expertise, both in its current business areas and in potential new markets, which could open up in around three years time. Since most new products or ventures are mainly derived from government sources, it requires the informal interaction with a network of personal contacts in government agencies and business organizations to identify new needs early enough to respond to them. As he puts it - "It's a question of knowing what is going on and what will work based upon CAE's expertise". Given the time-scales of government procurement cycles, it is crucial to have developed an overall approach to satisfying a new need before an RFP is issued. By that late date, potential bidders on the proposal must have done much of the "spade-work" required if they are to respond in a timely competitive manner.

Once he has perceived such a need, Mike Rowlands next identifies people in R&D/E who could be challenged and excited by the opportunity it offers. He approaches them informally (which is always possible in the company's "open door" culture) to discuss it and "bounce-off ideas" between each of them. If his enthusiasm is shared by others this guaranteees the internal momentum for the new project/product idea. The people involved then develop a project proposal which is submitted for approval to the R&D Review Committee. If approved, it is then typically funded from the internal R&D budget.

Several of CAE's current projects and product ranges (described later) began in this way. These include the joint venture with United Airlines and others, supported by the US airforce, to develop a simulator for the C5B cargo 'plane and the Boeing 727 Phase III simulator, funded by the FAA. The former project involves the development of a new approach to military training and funding was won in competition with Link and other US airlines. The control systems business also began in this way, including products for the Canadian naval patrol frigate programme. The need for new automated control systems for naval ships was identified well ahead of the RFP stage. Primary development was performed in the Department of National Defence (DND) establishments and it was perceived that there was no Canadian company capable of performing the advanced prototype development and manufacturing that would be needed. CAE recognized that it had the development capabilities in real-time software, displays and man-machine interfaces etc. required so targetted onto this need, initially through internal R&D funding. The company's anticipatory efforts were rewarded with contracts from DND for both the advanced development prototype and later the manufacturing of systems for installation on frigates.

Individual engineering projects are performed following a successful bid on an RFP. The company will only enjoy continued success provided such bids are priced competitively but sufficiently high to ensure an acceptable profit margin. This means that, when the bid is prepared, the project costs must be estimated as accurately as possible (recall steps 8 to 10 in Winning Simulator Orders). Too high an estimate could yield an uncompetitive bid price whilst too low a one could lead to a "successful" bid on a project which is later completed unprofitably by the company. Estimation accuracy varies between projects, depending upon the degree of technical novelty and therefore uncertainty involved, but the estimation process seeks to ensure that they are as accurate as the situation allows. This is achieved by the company's historical cost recording system.

Computerized records of the estimated and actual costs and times, broken down by activities and weeks, are held by the Estimating Department in Engineering. When a bid is prepared (typically by a Group Head) he estimates costs based upon his own and others personal experiences plus the information provided by these records. When a bid is successful and the project goes ahead, its costs are recorded weakly by activities and stored in the Estimating Department's computerized system to augment the historical records. All such project costs are also reported every three months to Head Office in Toronto. This recording system ensures that estimates are as accurate as the underlying uncertainties allow, not infrequently, within 20% of the costs actually incurred.

Engineering and Manufacturing

Both Engineering and Manufacturing report to the VP of Operations because, for engineering (as against R&D) projects, these two functions are closely intertwined. The end-outcome of an engineering project, such as a flight simulator, is a "one-off" complex project which incorporates many novel hard- and software features, so that "engineering" and "manufacturing" are not clearly delineated.

The production of a simulator takes an average of two years, although prototypes (a manufacturer's first shot at a particular aircraft type) take between 28-30 months. Each simulator order is different. Although a familiar aircraft might be ordered, because each airline has its own configuration requirements and philosophy of training, exact copies were unusual.

Upon receiving a simulator order, a project manager and engineer are appointed and fabrication begins immediately if CAE has made the type before. If not, research into flight data and cockpit layout comes first. Long lead-time items are the aircraft parts and instruments, computer, integrated circuits and sheet metal. There is no stockpiling because of the low-volume production, so occasionally these long lead-times cause problems.

In an attempt to keep costs down, CAE currently produces three basic sizes of motion system - utilising largely common components. Because of this approach, fabrication of the motion system can begin very quickly. In view of the significant value of bought-in parts, CAE makes every effort to make components itself wherever practical. All machining, sheet metal work and welding is done in-house. Electronics cabinets and moulds for the fibre-glass aircraft shells are also produced by CAE, as are the integrated circuit boards and interfacing.

Software is standardized where possible - in areas independent of the individual aircraft. A modular software approach has been adopted for the training instructor stations, so that different facilities can easily be made available for different customers. The motion software is standard, with the addition of individual geometric and customer requirements.

Most customers defer their choice of a visual system until later in the production process. As already noted, CAE decided - on the advent of computer generated visuals - not to develop such a system, judging it best to put money into other major subsystems of the flight simulator. The company can thereby offer customers a wide variety of visuals to choose from, since it has experience of integrating them all into its simulators.

In for example, May 1983, the following aircraft simulators were under production in CAE's high-bay facility:

Military aircraft

- McDonnell Douglas CF-18s for the Canadian Armed Forces (3 on order)
- A complex of four Agusta/Bell AB 205 helicopters for the Italian army
- Panavia Tornados for the West German and Italian air forces - 2 each.

Commercial aircraft

- McDonnell Douglas DC-10-15 for Mexicana (McDonnell Douglas Vital 4 visual system)
- Airbus Industrie A310 for Lufthansa Airlines (Rediffusion SPV visuals)
- Another A310 for KLM-Royal Dutch Airlines (Link Image 2 visuals)
- McDonnell Douglas DC-10-30 for Viasa (Link day/night visuals)
- McDonnell Douglas DC-9-80 for Swissair (Hitachi Bestview visuals)
- Boeing 747 for Korean Air Lines (McDonnell Douglas Vital 4 visuals)

The sequences of operations are outlined in Exhibit XII and illustrated in more detail in Exhibit XIII. Once (say a flight simulator) order is accepted work begins (separately and in parallel) on the hardware and software, based upon the designs prepared in response to the originating RFP and any changes to these agreed with the customer. This involves considerable drafting work which is partially performed on automatic drafting machines. Once the hardware design is completed it is released to Manufacturing for fabrication.

Flight simulators are fabricated from authentic parts from the simulated aircraft (sometimes cannabalised from crashed 'planes), internally moulded and manufactured and externally purchased items (including the visual display systems as mentioned earlier). Apart from these visual display systems, electronic hardware is designed and assembled internally.

Once the hardware has been fabricated it returns to Engineering for testing. This first involves "hardware testing" - confirming that the electronics, mechanical and hydraulic systems etc. operate to specifications. By this time Systems Engineering will have developed the software and it is now integrated with hardware to "drive" the latter. After simulator testing has been completed in-house, the product is transferred to the customer's site and a testing programme is repeated there, prior to customer acceptance.

Recent Trends

One notable recent success for CAE was the winning of the FAA's first simulator order (see Exhibit XIV). The FAA's 727 simulator was planned for research usage. The order was signed in February 1983 - about 12months after CAE's response to the initial RFP.

CAE did not have a great deal of pre-bid confidence in making this U.S. government sale, since it was considered unlikely that a well known agency such as the Federal Aviation Agency would buy outside the country. However, the bid was a two-step process - it first being necessary to overcome the technical acceptability criteria. CAE's compliant proposal was the only response received satisfying these criteria. The situation had changed and that which had been an open competition was now to be a negotiated order. Although things moved slowly, the two parties came to agree upon the terms and conditions for the simulator. Although the initial budget approved for the simulator was U.S. $4.8 million, this had been established much earlier and was inconsistent with the specifications issued. The eventual price to satisfy all requirements was U.S. $7.2 million!

CAE executives felt that the Phase III certification at United had really given them a technological edge in their dealings with the FAA, and hoped that this would influence future sales negotiations with airlines and aircraft manufacturers.

Because of the financial climate, airlines were increasingly hardnosed in their purchasing behaviour. It was felt that most of the simulator manufacturers faced fairly similar cost structures, although CAE's lack of a visual system lost them some room for manoeuvre. Then again, depending upon currency movements, certain manufacturers were at a cost advantage over others in their bought-in component purchases.

Another factor was influential too - this being financing. CAE had experienced extreme difficulty in this area. When interest rates were at record levels in 1981 and 1982 some sales had been lost because of more aggressive financing offered by Rediffusion (through Britain's Export Credit Guarantees Department) than CAE was able to arrange with the Export Development Corporation in Ottawa. Since interest levels fell by the end of 1982, however, this problem has receded.

Generally speaking, CAE executives were optimistic about gaining a good share of future commercial simulator orders. With Phase III certification, the FAA order and an excellent delivery record on recent installations, the company was in a very competitive position.

Looking to the Future

CAE had done well as a company. It had grown from about 400 employees in 1976 to 1700 in 1983. The simulator business had been very important in this growth process; the company achieving a good share of the available commercial business between 1965 and 1984 (although a number of barren years were experienced - see Exhibit XV).

Fortunately, the decline in commercial simulator orders had coincided with a seeming reduction in the number of 'serious' competitors. Manufacturers still seeking orders were, however, very aggressive in their pursuit. Rediffusion in particular, had been very successful over the last four years or so, due to competitive financing and the strength of the U.S. and Canadian dollar against sterling.

CAE plans recognized that annual simulator orders for airlines would probably not rise higher than 10-15 in the near future. They were, as a result, exploring new avenues for business growth. One of the more obvious and attractive options was to increase the volume of military simulator business, which had in the previous decade been about equal to civil simulator business. CAE had always been involved in this market and as military forces around the world became more conscious of the value of simulators in flight and combat training, more emphasis was being placed in this direction.

Military flight simulators. Military and commercial markets were quite different from one another. As noted already, the commercial market was made up of a large number of international buyers whose needs could be tracked and anticipated. As a group, commercial simulator buyers and their needs were pretty similar. In contrast, military needs and buyers varied from country to country. A company had to be sensitive to changing needs in a country or it might miss a military sale. Because of this, agents were an important part of a selling company's organization, for they frequently could 'open' doors as well as being able to uncover opportunities because they were on-the-spot. Military sales tended to occur where the company established and exploited a particular 'niche' in the market.

The selling cycle also differed between the two markets. Sometimes a commercial sale was made within six months of the need emerging. Military sales often took three years or more, because requirements had to be defined, approval sought, budgets established, and the procurement process set in motion.

As the military forces of the world re-equipped, CAE saw the opportunity to increase future sales and profits. Military simulator orders tended to be more profitable than commercial orders, for a number of reasons. First, because each buyer tended to have unique simulator needs, more latitude existed with regard to price. Second, the military purchased a lot of training instruction and spares. Both provide good profit for the manufacturer.

Canadian Military Sales. CAE was looking forward to doing more business with the Canadian Armed Forces. It had sold simulators and MAD equipment in the past but the volume of orders had not been large, mostly because military requirements had been small in each area. With air and naval re-equipment taking place, however, CAE was actively pursuing new business. It was exploring the possibility of becoming a supplier of a software support facility for the F18 fighter plane on-board avionics, and an on-board control machine system for the planned naval frigates. Each of these activities involved taking established CAE technology into new fields of application. The F18 provided a new application for CAE training systems and equipment, while the frigate programme did the same for the company's control systems.

Robotics. Another field for investigation is robotics. CAE's skills with special purpose machinery and large-scale software intensive systems led them to look at robotics. It was conceivable that the company would produce machinery for use in mining and underwater operations in the next few years.

Behind each of these potential developments was the view that CAE's skills lay in 'real-time computer control systems.' This has been the common denominator to all their activities since the first digital flight simulator in 1965. Company officers believed that CAE was the largest real-time computer systems house in Canada. Over the years, considerable experience had been developed in different application areas e.g., simulators, control systems; with a wide variety of processors (either specified by CAE or the customer); plus expertise in multiple processor systems. The multiple processor skills had started when CAE learned how to build real-time dual computer systems in their control system work for Ontario Hydro's Pickering Nuclear Power Station. Currently under manufacture were two pieces of equipment with quad computers - a nuclear power simulator and a CF-18 fighter simulator. This multiple processor capabilty was probably unique in Canada and felt to be unique in the world.

Other Projects

One R&D study contract is sponsored by the then Department of Industry, Trade and Commerce (now DRIE) and the USAF Human Resources Laboratory. This involved the development of a helmet display visual system. A large portion of the cost of a flight simulator is accounted for by the visual scene generation system which normally provides through-the-window images. This is particularly true in the case of military simulators where realistic daylight scenes are required for a wide spectrum of conditions including normal take off and landing, carrier landing, low-level terrain - following flying, air-to-air refuelling, etc. The development uses fibre-optic techniques to transmit a scene to the pilot's visor with a wide field of view high resolution display which is slaved (or follows) the pilot's head and eye positions. The goal of this project is to provide a low cost, portable trainer for pre-combat training. This should lead to improved combat readiness and a reduction in the high initial losses that characterize forces that lack recent combat experience. Early results from this research are encouraging.

Work was also underway on computerized instruction. In both flight and energy system simulators, an instructor has a heavy workload to observe the current state of the aircraft or plant, to plan a lesson and to create appropriate malfunctions or operating conditions, to observe the pilot or operator, to assess performance and to provide instruction or assistance. The computer can be used to assist in or, in fact, to perform any or all of these tasks. Computer - based (CBT), computer - assisted (CAT) and computer - managed training (CMT) projects are aimed at this problem. A CBT system has been developed in conjunction with United Airlines - this growing out of the Phase III certification programme. The CAT and CMT systems are under development, the former under a PILP grant from the NRC.

Other investigations at the present time involve:

1. Determination of the requirements for a tank simulator. This study contract is with DND.

2. Development of a microprocessor-based trainer for light aircraft in the field of general aviation. This contract is held by Concordia University, supported by CAE and funded by NSERC.

3. Proposals for process control trainers based on CMT. For example, training operators at a heavy water plant using interactive computer-graphic displays.

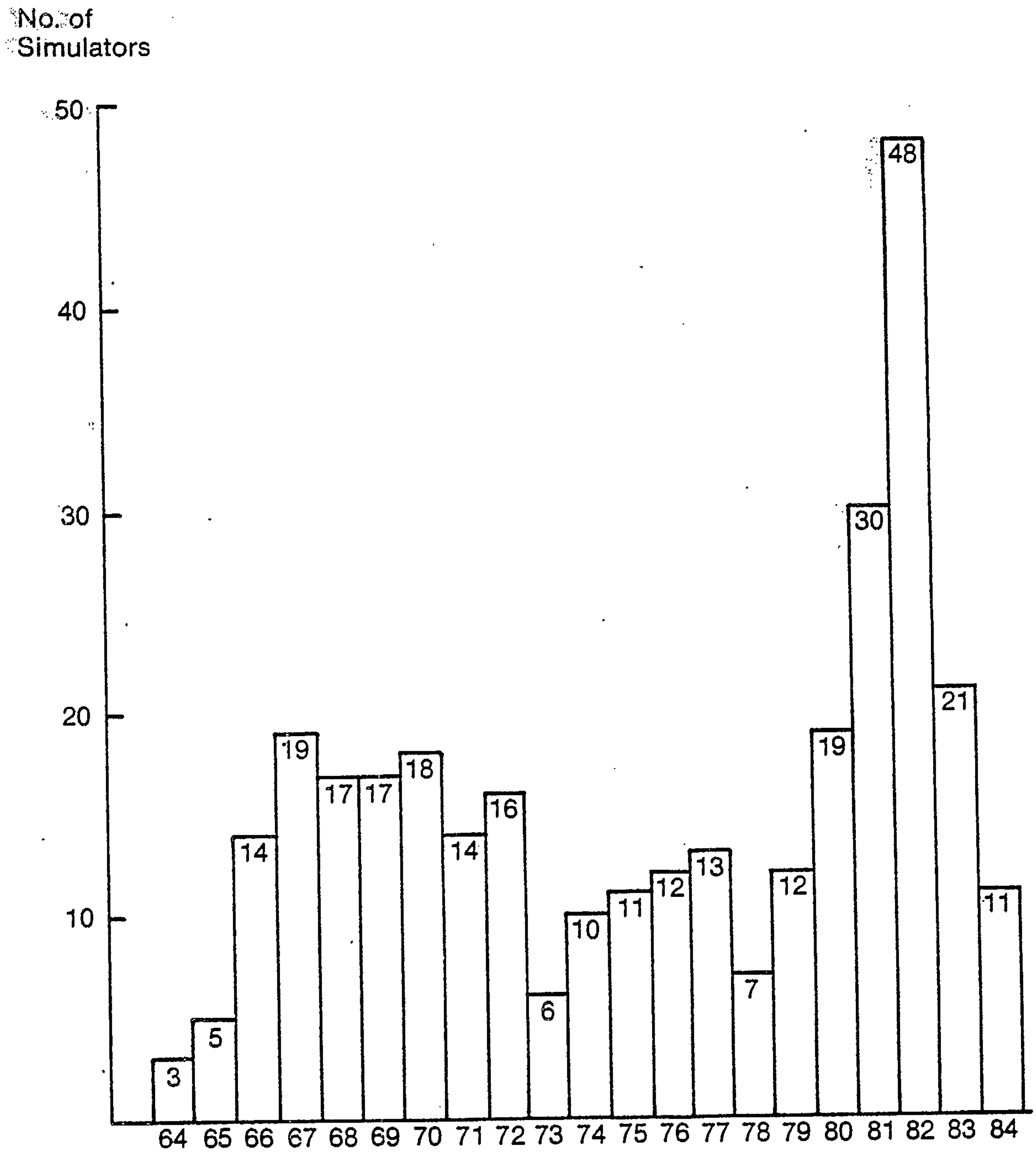
Commercial Flight Simulators. Although this market was smaller in 1983 than two years earlier (Exhibit XV), CAE were still actively trying to boost their level of market penetration. While not always the low-cost bidder, CAE certainly had an enviable technical reputation. Several airlines that had awarded bids to other producers recently placed subsequent orders with CAE. This augered well for the future.

Within the commercial simulator market, CAE saw potential for sales to commuter airlines. At the moment, training was carried out during regular flights but as commuter planes become more complex and the FAA got more interested in training, simulator training was a possibility. There would need to be a change in approach to this market, however, because the cost of present simulators sometimes exceeded that of the commuter aircraft itself. The economics of the situation demanded a different approach then, and CAE was thinking how it might approach such a market.

These thoughts about the future occupied senior management at CAE in late 1984. They were anxious to continue the successes of the past. As many of the upper-level officers had been with the firm for numerous years, they realised the challenge this presented.

Exhibit I

AIRLINE FLIGHT SIMULATORS BY DATE OF SERVICE ENTRY



Source: Derived from simulator census data - Flight International, 19 February, 1983.

Exhibit II

CAE INDUSTRIES LTD.-
SUBSIDIARY DIVISIONS

Electronics and Aviation

- CAE Electronics Ltd. (Montreal, Quebec)
- CAE Electronics GmbH (Stolberg, West Germany) Established 1961 to maintain CAE-built simulators in Western Europe.
- North West Industries Limited (Edmonton, Alta.) Acquired 1962. Aircraft maintenance, repair, overhaul and modification - commercial and military.

Automotive

- Webster Mfg. (London) Limited (London, Ont.) Acquired 1974. Major manufacturer of high precision zinc diecast products
- Accurcast Die Casting Limited (Wallaceburg, Ont.) Acquired 1975. Aluminum diecast products
- CAE Diecast Ltd. (St. Catherines, Ont.) Formed 1978, to produce aluminum diecast engine components
- CAE Magnesium Products (Strathroy, Ont.) Formed 1981 to produce hightweight magnesium diecastings.

Manufacturing

- CAE Machinery Ltd. (Vancouver, B.C.) Acquired 1965. Manufactures a line of machinery for the forest products industry
- Canadian Bronze Company Limited (Winnipeg, Man.) Acquired 1963. Operates a large foundry for bronze and aluminum products
- USP Industries, Inc. (Lennoxville, Que.) Acquired 1965. Produces screen plates for various industries. Chrome plating and foundry facilities
- CAE Metal Abrasive (Welland, Ont.) Formed in 1976 to operate Canada's only metal abrasive manufacturing facility
- CAE Fibreglass Products (Edmonton, Alta.) Established in 1976 to manufacture fiberglass reinforced pipes and tanks for western customers
- CAE Bellville Ltd. (Belleville, Ont.) Established in 1983 to manufacture fiberglass reinforced pipes and tanks for eastern customers
- CAE Journapack (Montreal, Que.) Acquired 1965. Produces lubricators used on railways.

Industrial distribution

- CAE - Morse (Toronto, Ont.) Acquired 1975. Distributes industrial machinery and equipment.

Source: Company documents.

Exhibit III

CAE INDUSTRIES LTD. - SEGMENT REVENUES AND INCOME

	Fiscal 1983		Fiscal 1982	
	$'000	%	$'000	%
Revenues				
Electronics and Aviation	$147,111	54.5	$125,398	46.2
Automotive parts	59,209	21.9	47,188	17.4
Manufacturing	39,950	13.7	47.618	17.5
Industrial distribution	26,560	9.8	51,309	18.9
Total	$269,828	100%	$271,513	100%
Income (Loss)				
Electronics and Aviation	$ 18,019	100.9	$ 15,520	92.5
Automotive parts	686	3.8	(3,104)	(18.5)
Manufacturing	1,285	7.2	3,552	21.2
Industrial distribution	(2,142)	(12.0)	806	4.8
Total	$ 17,848	100%	$ 16,774	100%

Source: Annual Report 1983

Exhibit IV

CAE INDUSTRIES LTD.
HISTORICAL SUMMARY

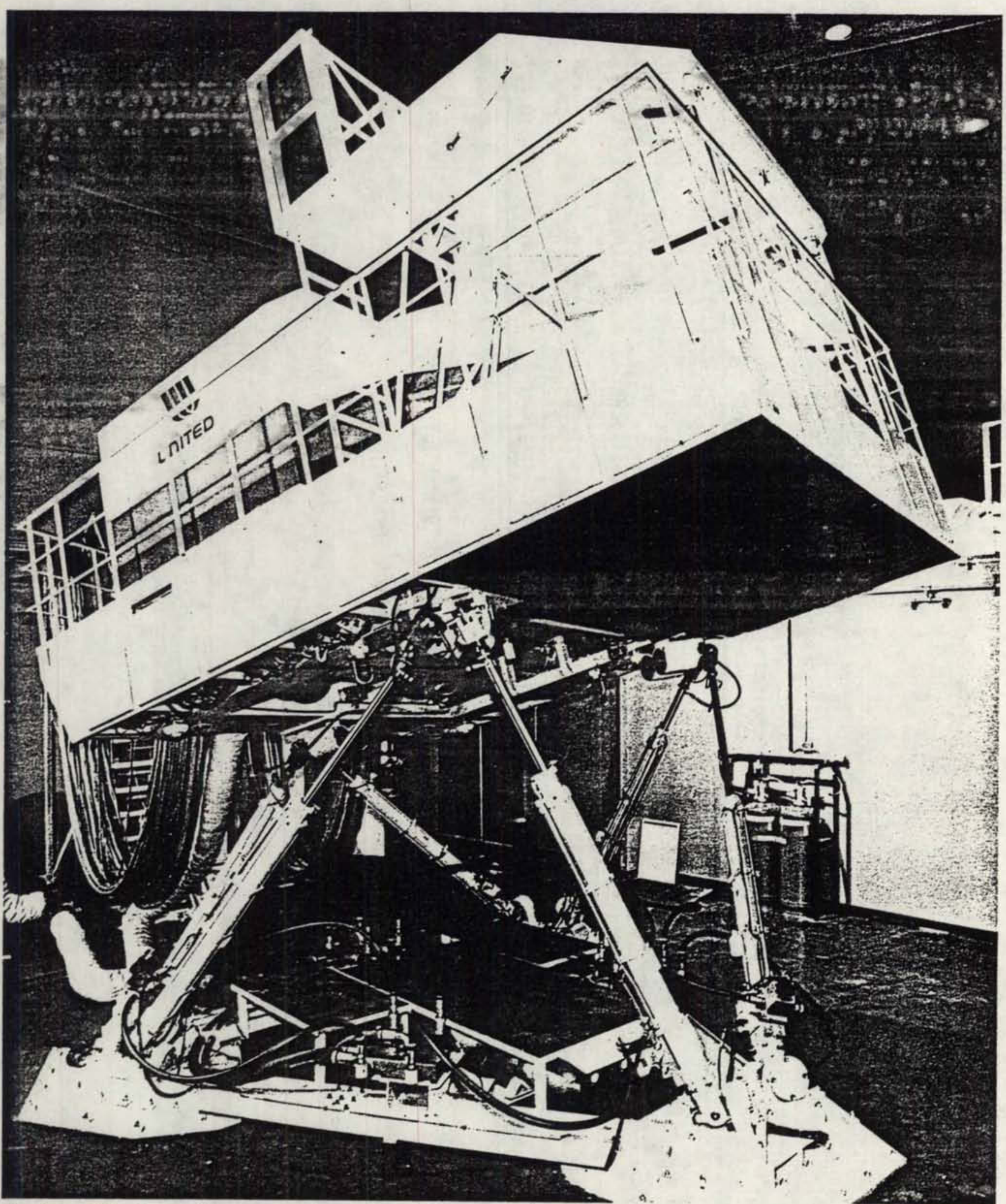
Fiscal Year	Total Assets	Shareholders' Equity	Fixed Assets	Long-term Debt	Revenue	Net Income from Operations	Earnings per Common share
			$1,000				$
1960	4,840	2,216	1,807	1,913	n.a.	507	1.53
1965	27,260	12,728	13,513	3,905	39,701	1,760	1.61
1970	36,131	12,981	9,582	3,294	45,413	811	0.39
1975	51,439	22,300	11,081	5,542	82,729	3,428	1.63
1980	117,452	37,359	36,355	27,593	238,508	8,339	1.45*
1981	146,549	44,329	46,676	26,347	292,615	9,639	1.67
1982	282,668	44,501	47,555	21,683	283,930	10,427	0.60*

Note: * Following 3-for-1 splits July 1979 and July 1981

Source: The Financial Post Corporation Service

Exhibit V

EXTERIOR OF BOEING 727 SIMULATOR



Boeing 727 Phase III approved simulator for United Airlines

Exhibit VI

COCKPIT VIEW - BOEING 727 SIMULATOR

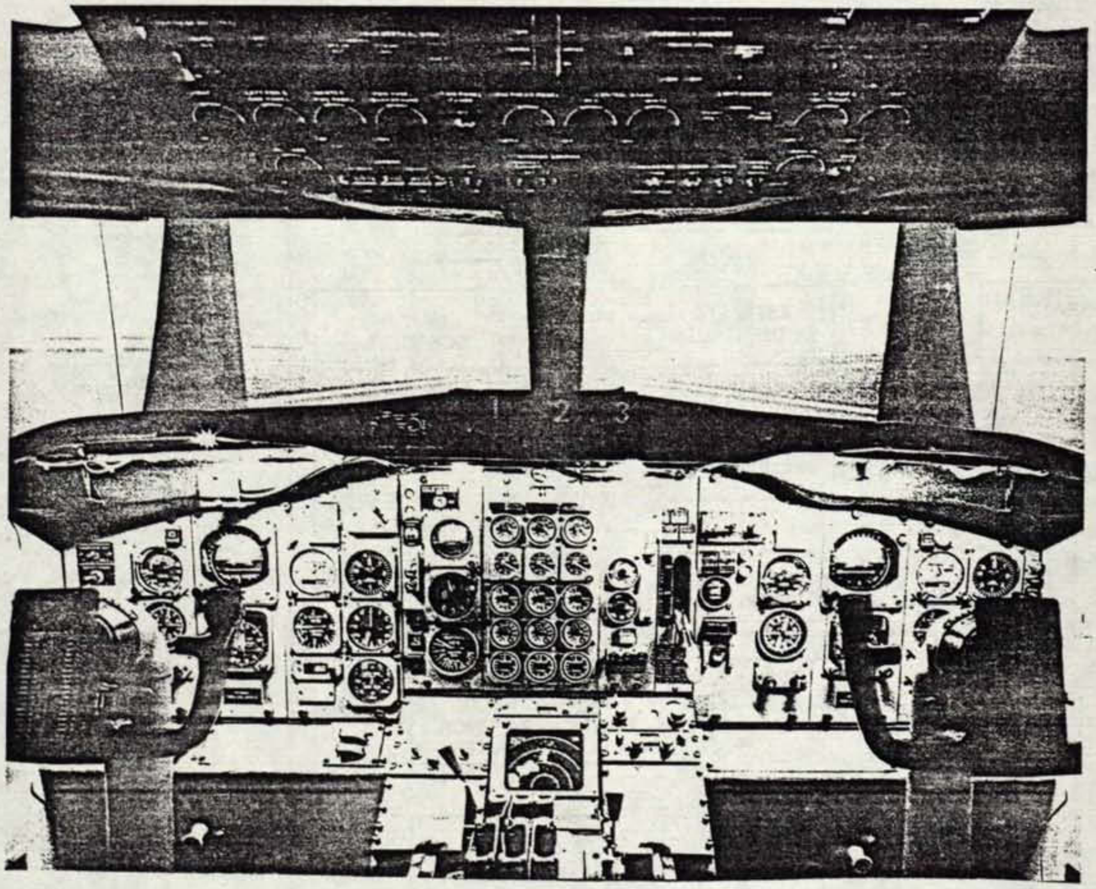
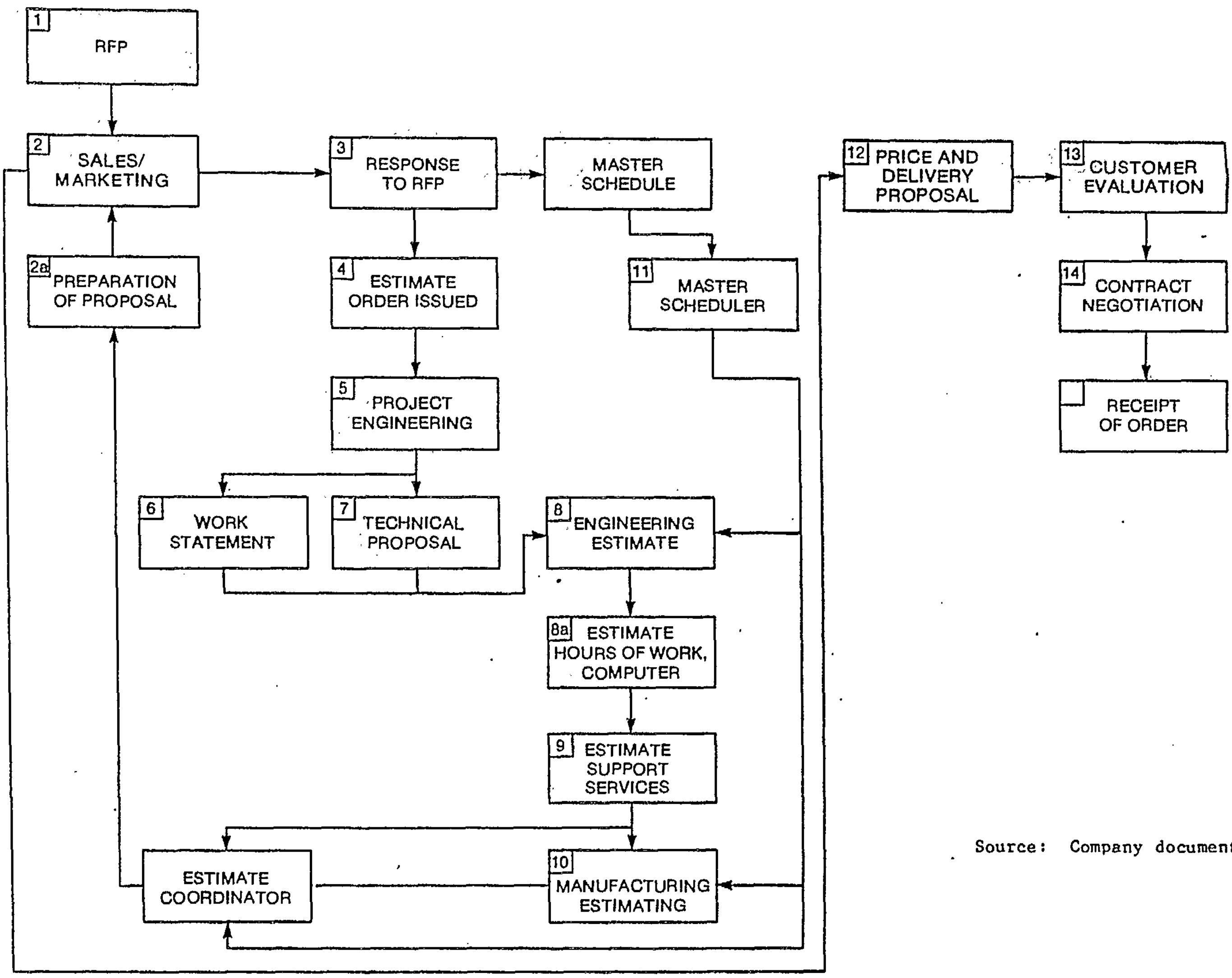


Exhibit VII

PREPARATION OF A FLIGHT SIMULATOR BID



Source: Company document

Exhibit VIII

AIRLINES AND MANUFACTURERS WITH CAE SIMULATORS

Airline	Number of simulators CAE	Total
Air Canada	7	10
Air India	1	2
Air New Zealand	2	5
Air Zaire	1	1
Britannia Airways (U.K.)	1	2
British Airways	4	15
CP Air (Canada)	3	5
Eastern Air Lines (U.S.)	1	11
Eastern Provincial Airways (Canada)	1	1
Fokker (Holland/U.S.)	1	2
Iberia (Spain)	2	5
Jugoslovenski Aerotransport (Yugoslavia)	1	1
KLM (Holland)	5	5
Korean Air Lines	1	1
KSS (KLM; SAS - Scandinavia, Swissair)	1	1
Lockheed (U.S.)	1	1
Lufthansa (W. Germany)	1	10
Malaysian Airline System	2	5
McDonnell Douglas (U.S.)	1	1
Mexicana (Mexico)	2	3
Olympic Airways (Greece)	1	3
Pacific Southwest Airlines (U.S.)	1	2
Piedmont Aviation (U.S.)	1	3
Republic Airlines (U.S.)	2	4
Royal Air Maroc (Morocco)	1	1
Singapore Airlines	2	4
Swissair	6	8
Toa Domestic Airlines (Japan)	1	2
Trans World Airlines (U.S.)	2	10
Union de Transports Aeriens (France)	2	2
United Airlines (U.S.)	5	15
Viasa (Venezuela)	1	1

Source: Derived from airline simulator census, Flight International, 19 February 1983.

Exhibit IX

SIGNIFICANT* AIRLINES AND MANUFACTUERS NOT USING CAE SIMULATORS

Airline	Number of Simulators Rediffusion	Link	Thomson	Total +
Air Lingus (Ireland)	2	1		3
Aeroformation (France)			5	5
Aerolineas Argentinas (Argentina)	4			4
Air France		3	2	5
Alitalia (Italy)	2	5		7
All Nippon Airways (Japan)	3	2		7
American Airlines (U.S.)	5	12		17
Ansett Airlines (Australia)		3		3
Boeing (U.S.)	6			9
Braniff (U.S.)	3			4
Cathay Pacific Airways (Hong Kong)	1	1		3
Continental Airlines (U.S.)		3		3
Delta Air Lines (U.S.)		9		9
Finnair (Finland)	2	1		3
Garuda (Indonesia)	2		1	5
Indian Airlines	2		1	3
Japan Air Lines	4			7
Northwest Orient Airlines (U.S.)		6		6
Pan American World Airways (U.S.)		9		10
Quantas Airways (Australia)		4		4
Saudia (Saudi Arabia)	2	1		3
Scandinavian Airlines System		4	1	6
South African Airways	6	1		7
Thai Airways International (Thailand)		2	1	3
Trans-Australia Airlines	2		1	3
U.S. Air	2	3		6
Varig (Brazil)	4			5
Western Air Lines (U.S.)	3			3

Notes:

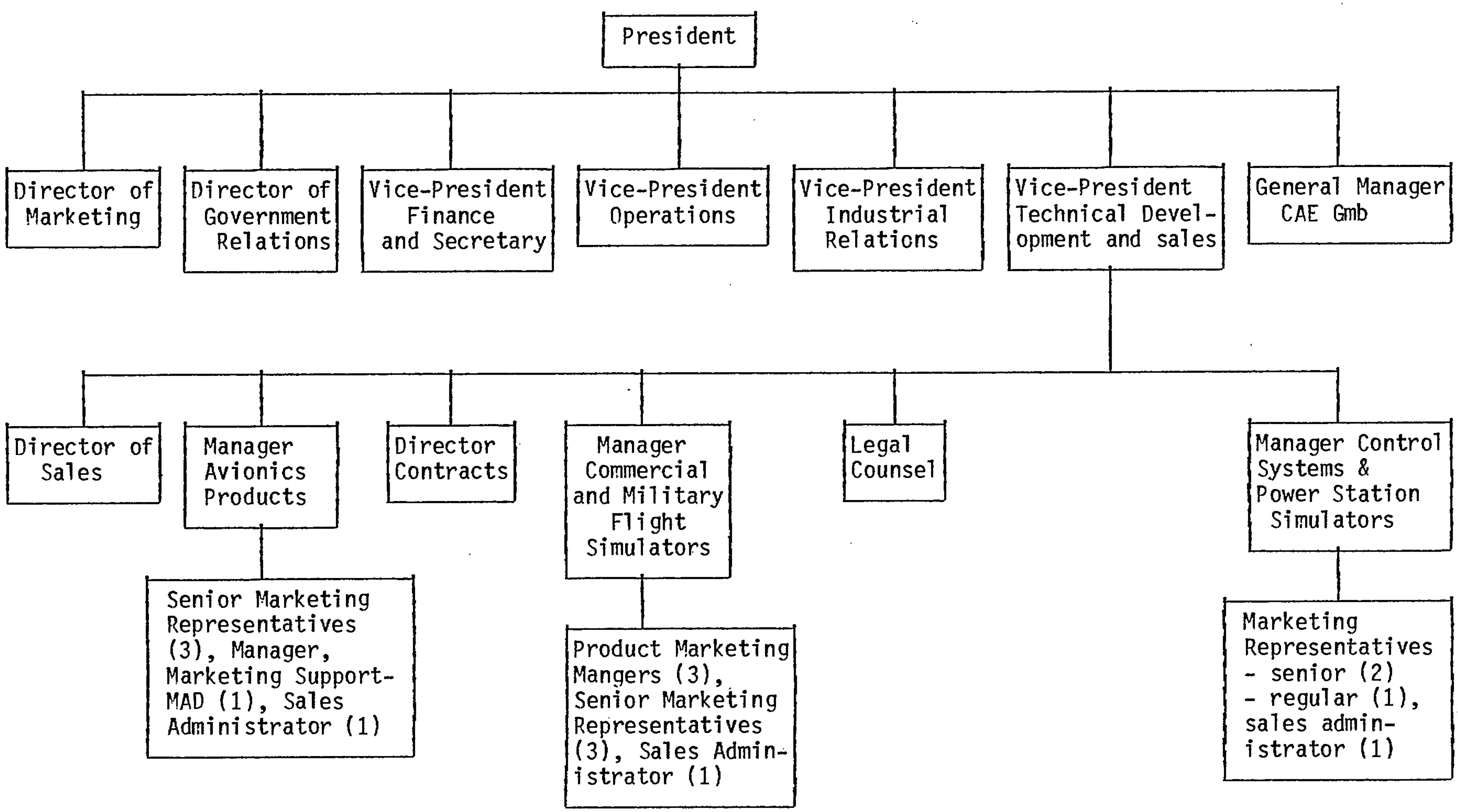
* Airlines with three or more simulators

\+ Total may not sum due to airline ownership of other manufacturers' simulators

Source: Derived from airline simulator census, Flight International, 19 February 1983.

Exhibit X

CAE ELECTRONICS LTD.
PARTIAL ORGANIZATION CHART



Source: Company document

Exhibit XI

CAE ELECTROMICS LTD.
PARTIAL ORGANIZATION CHART

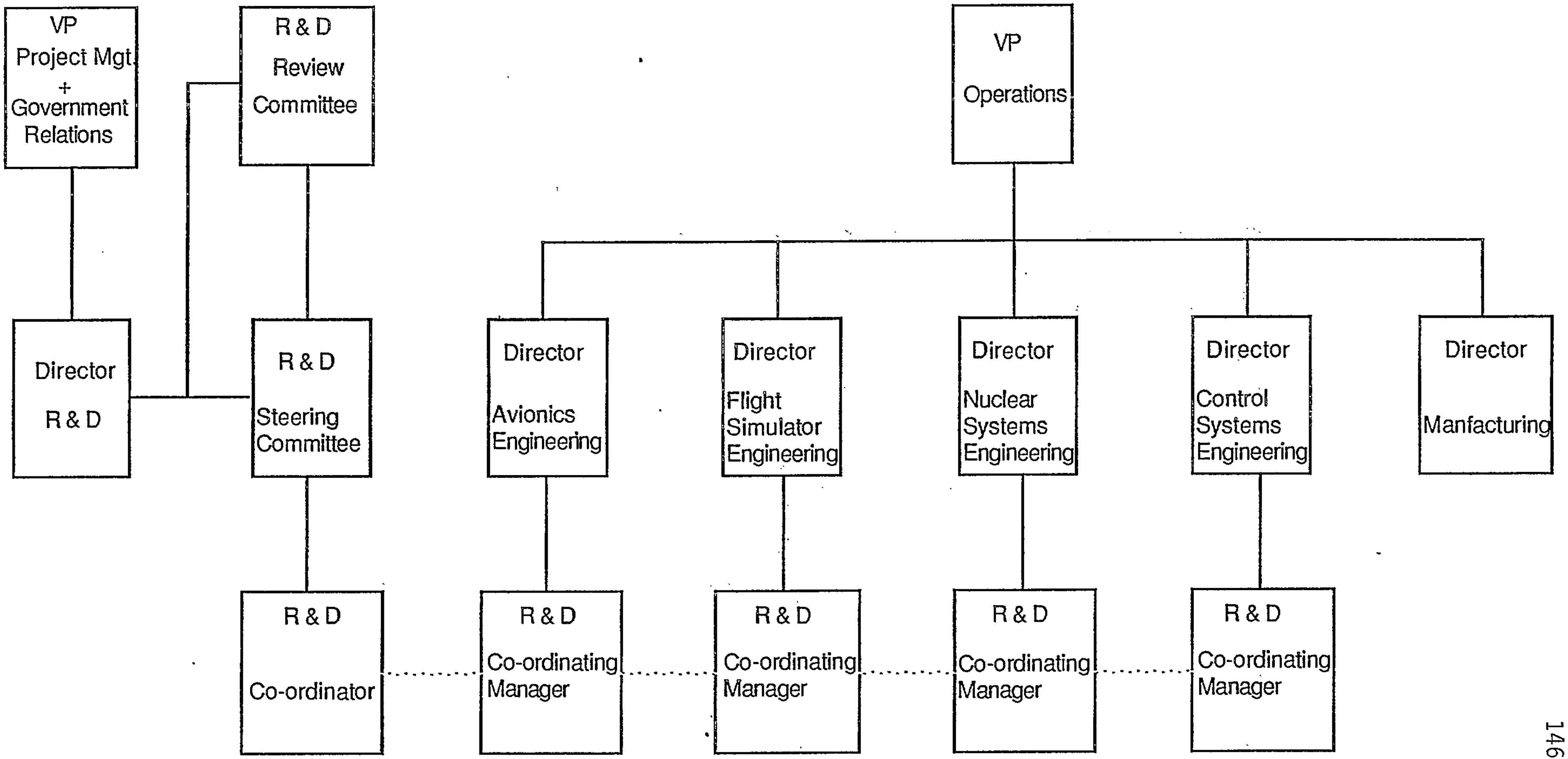
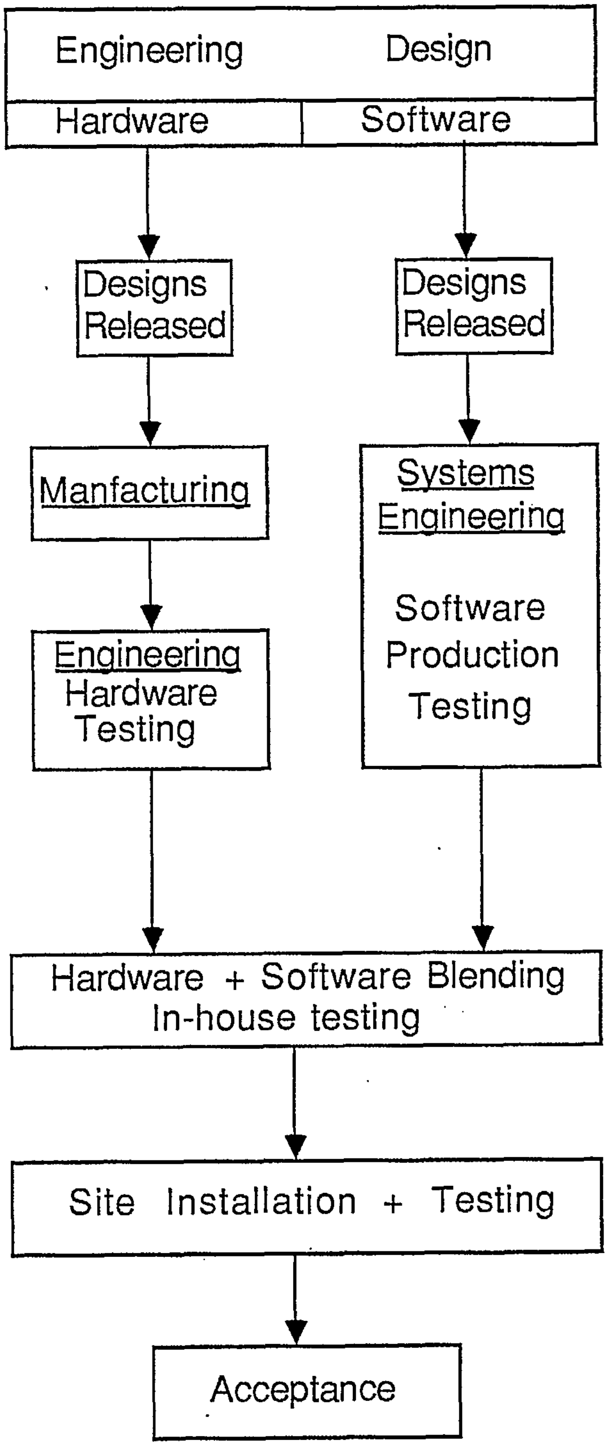


Exhibit XII

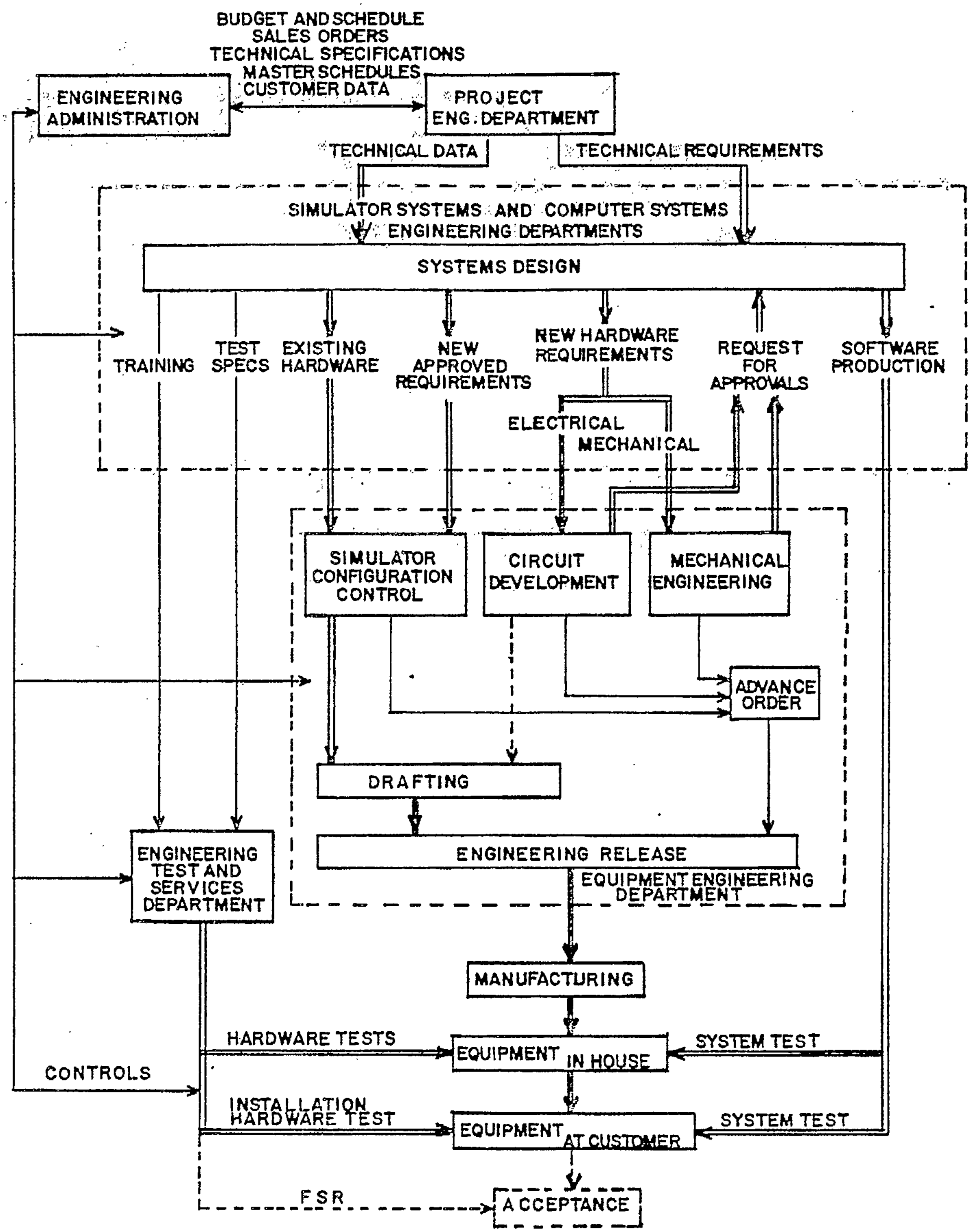
SIMPLIFIED PRODUCTION PROCESS



(See next Exhibit for more details)

Exhibit XIII

THE FLIGHT SIMULATOR PRODUCTION PROCESS



Source: Company document

Exhibit XIV

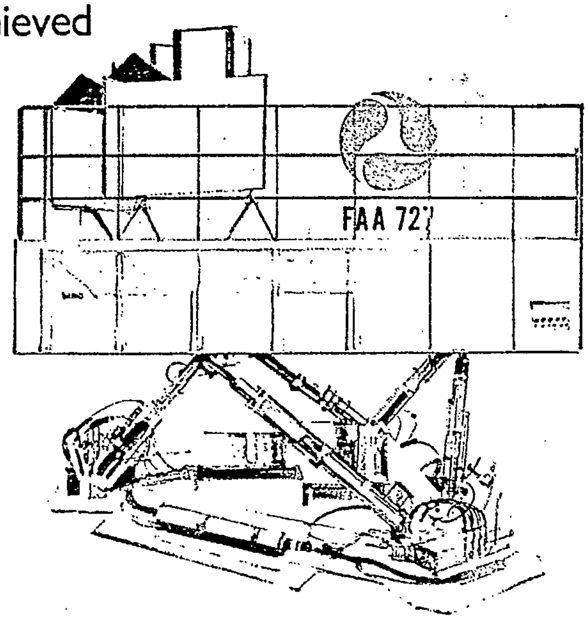
FAA ORDER PROMOTIONAL

The FAA selects CAE

to supply their Boeing 727 flight simulator

CAE recognized the importance to the airline industry of the U.S. Federal Aviation Administration Advanced Simulation Plan when it was published in 1980, and proceeded to incorporate its exacting specifications into the design and production of current flight simulators. As a result, an impressive number of CAE simulators have achieved Phase I and II certification and one, a CAE 727, is the world's first – and only – Phase III simulator.

CAE is proud of its relationship with the FAA – one that has greatly enhanced the quality and importance of simulator training.



CAE ELECTRONICS LTD.

cae

A subsidiary of CAE Industries Ltd.

P.O. Box 1800, St-Laurent, Québec, Canada H4L 4X4 Tel. (514) 341-6780 TLX 05-824856 TWX 610-422-3063

Exhibit XV

AIRLINE AND MANUFACTURER SIMULATORS BY DATE OF SERVICE ENTRY

Date of Service Entry	CAE	Link	Rediffusion	3 Company Total	Grand Total
1964	0	0	2	2	3
1965	0	1	4	5	5
1966	3	7	3	13	14
1967	2	12	3	17	19
1968	3	6	5	14	17
1969	1	10	3	14	17
1970	3	6	3	12	18
1971	2	5	6	13	14
1972	5	5	4	14	16
1973	0	3	2	5	6
1974	0	1	7	8	10
1975	4	5	1	10	11
1976	3	2	6	11	12
1977	3	5	5	13	13
1978	0	1	6	7	7
1979	0	6	5	11	12
1980	6	8	2	16	19
1981	7	9	10	26	29
1982	17	9	15	41	48
1983	2	7	5	14	21
1984	3	0	6	9	11

Source: Derived from simulator census data - Flight International, 19 February, 1983.

IMPERIAL OIL LIMITED (A) - THE NMP PROJECT

"You're from Research, aren't you? What on earth are you doing here? How can you help us?"

It was with these words that John Taylor, Manager of lube plant operations at the large Esso refinery at Fawley, Southampton Water, England greeted Tony White from Esso's Research Department in Sarnia, Canada. Dr. White (with a PhD in chemistry) had crossed the Atlantic to join a small "start-up" team which would be responsible for introducing a new solvent (NMP) into the Esso lubricating oil (lube in oilmen's jargon) refining process at Fawley. The date was July 4, 1975. Not a public holiday in either Britain or Canada -- though some believe that it could be celebrated as "Thanksgiving Day" in those realms! The task for Dr. White represented the culmination of some eight years of research efforts by him and his colleagues at the Sarnia Research Department. Fawley was the first lube plant to test out the new solvent in mainstream operations. If NMP lived up to the promise of bench level and pilot studies it would offer impressive benefits

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This case was prepared by Professors Michael Martin and Philip Rosson of Dalhousie University as a basis for class discussion rather than to illustrate effective or ineffective handling of an administrative situation. Some of the data and information have been changed to preserve commercial confidentiality. The authors gratefully acknowledge the financial support of the Federal Department of Regional Industrial Expansion, Office of Industrial Innovation in the development of the case.

(in improved plant safety and reduced environmental concerns, as well as direct dollar savings) not only to Fawley lube processing, but also to similar plants in Exxon refineries throughout the world, plus potential licensing fees from other lube processors. If it failed it would represent a write-off of some five to ten man years of research effort plus the cost of hardware at Sarnia, as well as the $2.5 million in cost of what would be an abortive conversion attempt at Fawley. Bruce Sankey, who headed up the project team at Sarnia, rated its chances of success as 60-70%.

From the opening remarks it might appear that Mr. Taylor was unsympathetic to the project. Nothing could be further from the truth. He was sold on the improved health and safety properties of NMP as much as any cost savings, so was keen to see his plant used as a "guinea pig" for Exxon world-wide. His remarks were spoken in jest (he has a puckish sense of humour) and within a week he was leaving Fawley for a three week annual vacation, reflecting a complete faith in the "start-up" team. His parting remarks were: "I'm off on three weeks holiday and expect to see NMP working when I get back. Don't blow up my plant whilst I'm away!"

Early Work

Dr. Sankey joined Esso at Sarnia with a PhD in chemical engineering in 1967 and immediately became involved in research on lube process solvents. In 1970 he took charge of the group performing this work, which Dr. White had also joined in 1969.

Lube products are extracted from crude oil in a series of steps which have evolved and improved over the past 60 years, based upon improved understanding of the chemistry and thermodynamics of the complex processes involved. Originally (until the late 1920s) crude was subjected to a single distillation step to obtain a lube with target range of boiling point (BP) and especially viscosity. Later (in the late 1920s and early 1930s) a solvent extraction step was added which removed undesirable compounds still present in the distillate. This removal improves thermal stability and hence reduces oil breakdown and deposit formation under end-use conditions. The change in viscosity it experiences between hot and cold environments is also reduced and additive response and colour stability are improved. Subsequent stages involve de-waxing and the removal of other undesirable residues. The efficacy of the solvent extraction stage critically affects the overall quality and hence profitability of the lube extraction process.

Early solvents tried included sulphur dioxide (alone or with benzene), chlorex, nitrobenzene, duo-sol, phenol and furfural. By the 1930s the last two of these were generally adopted for widespread use. Furfural is a by-product of cereal production and is sold by the Quaker Oats Company. It was the solvent adopted by Shell and Texaco who patented and licensed it out to others during the 1930s. Exxon preferred phenol, which was developed in Sarnia and also patented and licensed at about the same time. Each has advantages and disadvantages. Furfural handles easier but its low thermal stability dictates more demanding solvent recovery requirements. Phenol is more toxic as it is rapidly absorbed into the blood stream if accidentally spilt on the skin and also causes serious burns.

Over this period the extraction was also improved by developing better solvent-feedstock mixing methods. In the late 1920s mixing was by "batch-contacting". That is, the two were mixed in a large vessel. After the solvent had partially extracted the aromatic and polar compounds, the two layers were separated out and the solvent recovered by boiling off and condensing it back to a liquid. Since the extraction process was often incomplete, repeated batch-contacting steps were often required. This could only be achieved by passing the product through a succession of batch-contacting vessels. A costly, cumbersome and hazardous process. In the 1930s the "mixer-settler" approach was introduced to allow continuous (rather than batch) operation of the extraction process. Originally the two liquids were mixed in a series of vessels and then allowed to settle, but by the 1940s the process was performed in a single large tower, fitted with a number of horizontal trays to promote contact between solvent and feed. A solvent stream entered from the top of the tower, whilst a feed stream entered from the bottom. They thus met and mixed in two counter-current streams, the extracted product (or "raffinate") leaving from the top of the tower while the heavier "extract" stream leaves from the bottom. Solvent is recovered from these streams by distillation to be recycled to the extraction tower. This configuration enables the process to operate in a continuous manner with resultant economies of equipment size, manpower, energy and solvent (see Exhibit I).

As was stated above, by the late 1930s the two commonly used solvents were phenol and furfural, but given their disadvantages, work continued in many places to try to find a better one and some were commercially tried. However, by the mid 1960s a clearly superior substitute had yet to be found and effort in this direction was begun at Sarnia for two reasons:

a) The booming economies of the 1960s increased the demand for lube products so, by then, lube processors were expected to run out of capacity in the fairly near future. Capacity could only be increased by the expensive step of commissioning new or expanded facilities or by increasing the efficiency of the extraction (yield) of lube oils at the existing facilities. Although some increases in yields could be obtained through the improved design of contacting towers, any major yield increase awaited the discovery and development of a better solvent.

b) At that time there was a review of the role and responsibilities of the R&D laboratories of Exxon affiliates throughout the world. One recommendation from this review was that the Research Department at Sarnia be assigned responsibility for Exxon's worldwide lube process research.

The Search for a Better Solvent

So, beginning in 1965, an exploratory research programme was launched at Sarnia to seek out a better solvent. The criteria of "betterness" were by no means clearly defined. The merit of a solvent can be judged by over twenty criteria or physical and chemical properties (see Exhibit II), including the yield of a given quality lube it extracts from a given feedstock. The chemistry of petroleum is very complex and still incompletely understood. Since not all of the underlying physical and chemical processes reach completion in "on-line" operations, one of the early exploratory avenues was to try to identify the maximum theoretical yield of the process with a given solvent. This work showed that the current yields then being obtained from phenol and furfural were nowhere near that maximum. This confirmed that a successful search for a better solvent offered a high pay-off.

During 1965-66 some 40 possible solvent chemicals were screened -- that is, subjected to appropriate tests. Several patents came out of that work, including coverage of the ultimate solvent, but this was ignored in favour of others which looked more promising at the time. Out of the approximately 40 screened, five looked promising enough for further work -- that is, larger-scale continuous pilot-unit processing -- and this work was performed in 1966-67.

Out of that work, attention was focussed on Solvent A, which looked attractive for two main reasons. First, it was readily available and fairly inexpensive. Second, it was cheap to recover from the solvent-feed mixture after the extraction process because a cheaper recovery method could be used. Most solvents (including phenol and furfural) are recovered from the mixture by distillation since they have lower BP's than lube. This method gives good solvent recovery rates, but consumes a lot of energy, and therefore money, in boiling off the solvent. With Solvent A another recovery approach was used. The mixture was heated to a relatively high temperature to perform the extraction (but below its Boiling Point), and then allowed to cool. The solvent separated out into a second layer as the liquid cooled. This method requires less energy and is therefore cheaper.

Unfortunately, these advantages were outweighed by other disadvantages. Although energy saving, this latter approach gives impure solvent. Since it is recycled frequently in actual lube processing operations, this is a critical disadvantage. Others discovered included poor thermal stability (also important because it would have to withstand frequent temperature changes) and an unattractive level of toxicity. Work on Solvent A was therefore abandoned at around the time Dr. Sankey joined the research team in 1967, and other possibilities were reconsidered.

NMP on the "Back-burner"

One solvent which had previously been screened was NMP, or N-methyl-2-pyrrolidone, another organic compound. NMP had not been seriously considered earlier because it was much more expensive than either phenol or Solvent A, and could only be obtained in small quantities. NMP cost 80c-$1/lb as compared to 15c/lb for phenol. However, once work on Solvent A had been abandoned, it was decided to undertake further investigations on NMP at the laboratory level.

The major advantages of NMP were that it gives a higher lube yield, is less toxic than phenol so easier handled, and is liquid at room temperature. The last property meant that it did not have to be always heated for handling, so it offered a potential saving in energy costs. Despite these advantages, it was realized that its much higher cost would preclude its commercial adoption by lube plants. Large quantities of solvent are required in a plant so the cost differential represented millions of dollars differential in plant set-up and operating costs. Work on NMP was therefore pursued on a curiosity-exploratory basis for three reasons:

a) Since its lower toxicity made it easier to handle, it was particularly useful at laboratory level experimentation where the small quantities required did not impose a significant cost burden.

b) The improved lube yield obtained from NMP provided a useful "yardstick" for judging the performance of phenol. An ideal solution would have been to make phenol behave like NMP -- thereby obtaining the improved performance with the low cost solvent. Comparative investigations were conducted on both solvents with this end in mind, and some patent coverage obtained.

From 1968 to the early 1970s a very modest level of effort was applied to NMP. Although several PhD's plus support technicians worked on it from time to time (including Bruce Sankey, and Tony White from 1969), no one spent more than 25% of his time on the project. Funding for it was essentially "bootlegged" from within the overall budget for lube process research. All R&D projects are subjected to annual performance reviews by senior management. Throughout this time the researchers maintained a steady output of positive results from further studies to ensure that the NMP project showed promise at an exploratory, low cost, research level. At the same time they maintained a low profile for the work, since they knew that operating managers would reject NMP as being too expensive. Their immediate superior at Sarnia, Dr. Jack Walker, also strongly supported these exploratory efforts. He is a good exploratory idea generator himself and participated in the identification of NMP as a potential solvent earlier, so his backing enhanced the credibility of the project at a more senior laboratory management level.

When he joined the project in 1969, Tony White was concerned with the underlying chemistry of the NMP solvent extraction, trying to discover why it gave a better yield than phenol. At the same time, Bruce Sankey was concerned with the engineering design of the extraction towers, including the settling trays. This work was of immediate relevance regardless of the solvent used, because at that time a new lube plant was being designed for the Sarnia refinery. The yield advantage of NMP at the laboratory level was confirmed at the scaled-up and pilot plant levels and other benefits were found. In the extractor trays the solvent and feed mix and settle. Mixtures were found to settle faster with NMP compared to phenol. This meant that the overall extraction process occurred more rapidly so that the throughput and hence the capacity of a given size and design of tower would be greater with NMP than phenol. From studies on a small experimental continuous settling unit, throughput rates were more than doubled.

In the years 1971-73, there was also a small but growing interest in NMP in Exxon Research and Engineering in Florham Park, New

Jersey, led by Jim Bushnell, head of the lube process engineering section. The New Jersey team started to make some preliminary economic evaluations of the process based on the Sarnia laboratory work as well as taking a first quick look at the engineering implications of the new solvent. However, by 1973 other external events were shaping NMP's future in a more dramatic way.

The Energy Crisis

In the fall of 1973, the first OPEC oil crisis quadrupled the price of crude oil from around $2.50/barrel to around $10/barrel, and the comparative costs of the two solvents changed significantly in favour of NMP. First, this meant that any increased yield had four times the dollar value it had before. Second, energy costs and therefore the energy savings benefits of NMP over phenol increased by the same factor. Third, the price of phenol is tied closely to crude prices, whereas NMP is a speciality chemical whose price remained unaffected. The price of phenol increased from 15c/lb to 25-30c/lb so the price gap between the two was reduced.

At about the same time, a lube plant worker in Singapore was tragically killed by phenol in an accident, and this focussed attention on its safety hazards. Other less serious accidents involving phenol had occurred elsewhere, emphasizing the need for a safer solvent. John Taylor at Fawley was particularly keen. He had had phenol related accidents in his plant, as well as some corrosion of heat exchangers which produced periodic solvent leaks. Moreover, phenol is a particularly noxious environmental pollutant which is highly toxic to fish life. All oil refineries (with or without lube plants) produce waste water containing some phenol, which must be treated (usually by biological oxidation) prior to discharge. By that time the U.K. parliament had passed environmental protection laws which incorporated stringent controls on the release of phenol. Fawley's treated effluent discharges into the Solent -- the stretch of water between Southern England and the Isle of Wight, which is an area rich in natural beauty and ecological variety as well as a mecca for yachtsmen from all over the world, including the Royal Family. The environmental protection authorities were therefore monitoring pollution levels in the Solent regularly and the refinery was thus sensitized to the serious consequences of an "upset" in the effluent treating facilities leading to a discharge of phenol contaminated effluent. The phenol lube plant, as a major potential source of toxic effluent, therefore came under increasing scrutiny by those at Fawley responsible for assuring the quality of the effluent streams being discharged into the Solent.

Given that situation, in 1973 Mr. Taylor flew over to Exxon Research and Engineering at New Jersey with the message: "Rip phenol out. I don't care what you put in, but I want phenol out!"

NMP on the "Front-burner"

At first sight the obvious replacement solvent would appear to have been furfural. A solvent which was commercially and technologically proven and lacked the toxicity of phenol. The thermal instability of furfural was, however, incompatible with the operating temperatures of the Fawley lube process. Therefore, this solution was technically infeasible without virtually replacing the lube plant -- an unacceptably expensive option -- so attention focussed on NMP. The impact of John Taylor's demand was to "light a fire" under the NMP project and move it into a high priority category.

Exxon Research and Engineering assigned an engineer full-time to work on the detailed design of an NMP plant. He required a mass of information on the thermodynamics and technology of the NMP extraction which was neither published in the literature nor available from the NMP manufacturers. Sarnia therefore stepped up their efforts to provide this information. Now the equivalent of one and a half full-time researchers (plus technician support) were assigned to the project to generate this information. Another option considered was the possibility of using a mixture of NMP and phenol. If a mixed solvent worked it was argued that NMP could be phased into a plant slowly as a replacement for phenol losses over time. Two experimental programmes were therefore launched -- one using 100% NMP and the other using a mixture of the two. The latter approach was rapidly revealed to be infeasible because it was discovered that certain mixtures of NMP and phenol boiled at a higher temperature than either NMP or phenol alone (that is, they formed what chemists call a high boiling-point azeotrope), so it was impossible to recover the NMP from the mixture. An unanticipated bonus from this work was the discovery that although phenol and water formed an azeotrope, NMP and water did not.

This meant that it would be much easier (and cheaper) to separate solvent and water in an NMP plant. Again this discovery made NMP look more promising. The possibility of using an NMP-furfural mixture was quickly rejected because of the thermal instability of the latter solvent.

Good thermal stability was a critical requirement for the solvent selected, since thermal decomposition increases solvent losses. Solvent is typically recycled five times daily (or over 1,800 times a year) in a plant over many years. Therefore solvent losses must be kept below the order of .001% to avoid unacceptable replenishment rates.* Historically, phenol loss had been higher than anticipated, though still below the acceptable limit. This higher loss was conjectured (but never proven) to be due to higher levels of thermal decomposition in actual operations than indicated in pilot studies.

The Christmas Crisis

Concern for NMP's viability was, however, aroused by information from one of its two primary suppliers, BASF of West Germany. Exxon engineers visited West Germany to discuss the project and BASF chemists there told them that NMP would not withstand the high temperatures experienced in the extraction process. It would "fall apart" into simple molecules. BASF's experiments were replicated at Sarnia and the same results were obtained. A sample of NMP was

* A .01% loss rate generates an approximate 17% solvent loss over a year, whereas a .001% rate generates a 2% loss.

maintained at 400°C (it would be raised to much higher temperatures in an extraction process) for 24 hours. At both BASF and Sarnia it decomposed into a black tarry mess. Tony White describes this as the worst moment in the project. He believes that had they been aware of this decomposition earlier (say in 1971) the project would have been abandoned. It would have proved impossible to justify further work to prove the manufacturer wrong.

It was the firm commitment given to Fawley to replace phenol there which kept the project alive. The researchers at Sarnia put on their "thinking caps" to identify an explanation of the decomposition process and a means of stopping it. It was attributed to an autocatalytic reaction occurring when NMP is maintained at an elevated temperature for some time. That raised the interesting and critical question as to whether this autocatalytic reaction would occur under the time/temperature combinations NMP would experience in an extraction process. During an extraction cycle NMP would be raised to a temperature well above 400°C but only for a very short time -- the order of a few milliseconds -- after which it would cool off again. Thus it would be heated to a high temperature for a few milliseconds about five times a day, or about once every five hours. The question was, would decomposition occur under these quite different conditions. That is, was it a cumulative decomposition which would slowly degrade NMP to produce a tarry material which would slowly seize up the plant, or did autocatalysis only occur when it was held at a high temperature for some continuous time? From their understanding of the chemistry involved, the researchers believed autocatalysis would not occur, but this was undoubtably a many million dollar question with an answer obtainable only by experiment.

The question was raised in late 1974 and an experiment was designed to answer it. A small pilot unit was built and run continuously for a three week period beginning in mid-December over the Christmas-New Year holiday period when the pilot plant normally shut down. The researchers celebrated Christmas with their families wondering whether the NMP project would survive into 1975. Fortunately the answer was favourable. The process had worked smoothly, confirming that autocatalysis did not occur under these conditions. The pilot run also confirmed earlier results which suggested that NMP was more stable than phenol and might be expected to incur lower losses in full-scale operations. However, given the increase in phenol losses over the scale-up from pilot unit to actual operations, the researchers had to admit that they could only offer an informed technological judgment that NMP would remain stable under actual operating conditions.

The thermodynamic studies performed in 1974 identified another advantage of NMP over phenol. NMP has a higher BP than phenol and initially it was thought that this would reduce the thermodynamic efficiency of an NMP versus phenol extraction process, thus increasing energy consumption. The detailed studies showed the reverse. Extraction using NMP is thermodynamically more efficient than that using phenol, particularly with the design configurations of the Fawley plant. These studies suggested that a 25% energy saving might be obtained when replacing phenol with NMP. Although such a conclusion had to be treated with caution, given that full-scale operating characeristics cannot confidently be predicted by extrapolation from laboratory level results and because the Fawley plant configuration was particularly favourable to NMP, its implications were of critical importance. The energy cost saving when added to those cited earlier implied that NMP extraction could be as cheap as or cheaper than phenol. That is, it might well offer cost savings as well as safety and environmental benefits. This significantly enhanced the status of the project. Whereas before its momentum had derived from John Taylor's determination to replace phenol at Fawley with NMP being chosen as the only viable alternative, now the context of that application changed. The installation of NMP extraction at Fawley could be viewed as a demonstration project. If the promise of the research and engineering studies were fulfilled, NMP could well replace phenol in Exxon lube extraction plants throughout the world, particularly as the Fawley application would yield a lot more data on its behaviour under actual operating conditions.

The Go/No Go Decision

These thoughts were in Bruce Sankey's mind when he flew to New York to attend (as Research's representative) a meeting with the Vice-President of Exxon Research and Engineering. Also present was Jim Bushnell to represent Engineering. The Vice-President asked each in turn whether he should recommend the installation of NMP at Fawley. Mr. Bushnell replied first with a confident "yes". He had been a strong advocate for the project in Exxon and its affiliates for several years. His views rightly carried considerable weight within the organization as a very experienced senior engineer in his area of expertise. Dr. Sankey replied with a slightly more cautious "yes", because of the technological uncertainties of scaling up from pilot to full production and the compression of development work from a normal period of years, into months. However, as stated at the beginning, he estimated the probability of success to be about 70% and he considered that an acceptable risk. If NMP failed and Fawley had to revert to phenol, it would incur a $1-3 million loss -- a sustainable loss for a corporation the size of Exxon. If it behaved up to expectations, the benefits of applying NMP extraction world-wide should run into the hundreds of millions of dollars. Although not a betting man, he recognized that it was worth laying a $3 bet on a horse at odds of over 100-3 in your favour, when its "form" told you it had at least a 70% chance of winning the race! Needless to say, the go-ahead was given for the installation of NMP at Fawley.

Much work remained to be done before installation later in the year. First, it was necessary to confirm that adequate supplies of the material would be available. This issue had already been addressed in 1974. The suppliers were BASF in West Germany and GAF of Houston, and installing NMP in Fawley would require six months of total manufacturing capacity. NMP is made from a raw material also used in the manufacture of several plastics. In the early 1970s it was fashionable to wear shoes with large plastic wedge heels and this end demand was consuming much of the raw material required for NMP.

Had this fashion continued, it could have delayed the project through constraining the NMP supply. Fortunately for the team, these heels had become unfashionable by 1975 so solvent supply could be guaranteed.

Second, plant engineers at Fawley required procedures for monitoring NMP losses during operations. The Sarnia team therefore had to develop analytical procedures which could be used reliably in a plant as compared to the research laboratory environment. Third, although NMP is much less toxic than phenol, it is a very powerful solvent, as well as a de-greasing agent which quickly removes skin grease on contact. So materials had to be identified which would resist its solvent and de-greasing action. It took some time to identify a resistant plastic for safety clothing (particularly gloves) to be worn by workers in the plant. Animal experiments had also shown that NMP causes conjunctivitis (inflammation of the eyes) so special safety goggles were designed.

Fourth, the issue of environmental aspects had to be addressed. The manufacturers supplied biodegradibility data which showed that it decomposed rapidly and harmlessly, and these data were confirmed at Sarnia. Since all extraction plants also have wastewater treatment systems, there appeared no danger of NMP becoming an environmental pollutant. Pollution risks were also reduced by the fact that NMP was still three to four times more expensive than phenol. This factor was an added incentive to increase efforts to reduce losses from random causes and from solvent residue left in the end product. The former could be minimized through care in installing, operating and maintaining the plant. As with thermal decomposition cited earlier, the latter could only be finally determined from actual operations. Laboratory level studies yielded a solvent residue of 50-60 ppm (parts per million), which would be economically acceptable. Unfortunately, given the technological uncertainty of up-scaling to full production, this figure could only be interpreted as a predicted residue range of between 5 and 350 ppm for actual operations. Were the actual residue to lie at the upper end of this range in actual operations it would significantly increase solvent loss and adversely influence its economics. In the event, the solvent residues monitored after the process had been installed at Fawley were consistently at the low end of the predicted range which in hindsight made the solvent loss assumptions, used in early economic analyses, unduly pessimistic.

The Fawley Application

The switch to NMP was timed to coincide with a major scheduled "turn around" of the Fawley lube plant. Such periodic shut downs (for routine maintenance) in continuously operated plants are essential for safe and reliable operation and are preceded by inventory build-up to minimize product supply disruptions. This "turn around" thus provided a window for making the conversion with the minimum impact on the plant's ability to supply customers. The Florham Park NMP engineer was dispatched to Fawley to work with the local engineering team planning the "turn around" to schedule the additional mechanical work necessitated by the decision to change extraction solvents. Once "on site" at Fawley, trans-Atlantic communications accelerated rapidly as he encountered numerous questions requiring resolution. Project planning had gone from the broad go/no go issues to worrying about the intimate details of every nut and bolt.

Tony White, together with a colleague from Exxon Engineering, travelled to Fawley two weeks before NMP installation in Summer 1975. One of his immediate tasks was to train operators in the new procedures required and warn them of what would happen when the new solvent was introduced. This task was especially important because, being familiar with phenol, operators were reluctant to change from it despite its safety hazards. NMP is a good de-coking solvent so, when it was first installed, it was expected that the end product would initially come out black as the NMP de-coked the heat exchangers. The operators were warned not to be shocked by this effect. Appreciating its de-coking properties, some operators used NMP to de-coke their automobile engines and its remarkable solvency properties were effectively utilized in putting back into service discarded paint brushes!

The new process was launched on July 4 and, sure enough, the initial product was coloured black as NMP performed its predicted de-coking action. However, within three hours it had cleared, the product met specifications and the new process was on-stream. The start-up team then began a three month measurement programme to determine key characteristics. The improved yield, energy consumption and settling-rate confirmed the optimal performance predicted from the laboratory studies. The solvent loss was also reduced by a factor of four when compared with phenol. The only significant property which failed to meet expectations was the water-solvent separation, which differed from laboratory experiment predictions. This caused concern because it was feared that water was entering the plant from an unknown source and would eventually disrupt the operation. Tony White cabled Bruce Sankey at Sarnia with a request for him to repeat these experiments and, within the limits of experimental error, the new results were consistent with the water-solvent characteristics observed at Fawley. Operators quickly learned how to operate the plant with NMP and rapidly decided that it was preferable to phenol. The rated capacity of the plant was increased by 25% and was now limited by downstream processing capacity rather than the extraction process itself. The cost of the conversion was $2.5 million, but the annual operating costs savings were over $500,000, plus the benefits of reduced safety and environmental pollution hazards. The achievements of all those concerned were recognized by no less a personage than H.M. the Queen. Esso was most honoured to receive the Queen's Award to Industry for technological innovation for the first application of the new technology at Fawley.

Exxon's Pay-off

Following this successful and award winning application at his plant, John Taylor became a strong advocate for the new process and helped sell it to other Exxon affiliates. There was a world-wide shortage of lube capacity in the mid-1970s so, given its proven increased yield, this factor too accelerated its adoption elsewhere.

Within ten years eight out of the ten Exxon lube processing plants, representing 95% of its lube processing capacity, had been converted to NMP. The remaining two plants were unsuitable for conversion. The process had also been licensed to other oil companies, so that it now accounts for some 25% of lube processing capacity world-wide. To date, the net present value of the project to the industry was estimated at over $150 million, obtained from an R&D expenditure of well under $5 million.

Members of the project team participated in the first few plant conversions, but later they were performed solely by engineering and operating personnel on a routine basis. The success of the Sarnia people in pioneering NMP and participating in its application in several plants created a new precedent. Before the project process researchers had worked through engineering rather than directly with operations. Since 1975 these researchers have been increasingly called upon to help operations managers to improve their plant performances, and can frequently be seen in Exxon plants. No longer would an operations manager, even in jest, say to one of them: "You're from Research, aren't you? How can you help us?"

EXHIBIT I

FLOW STREAM OF EXTRACTION UNIT

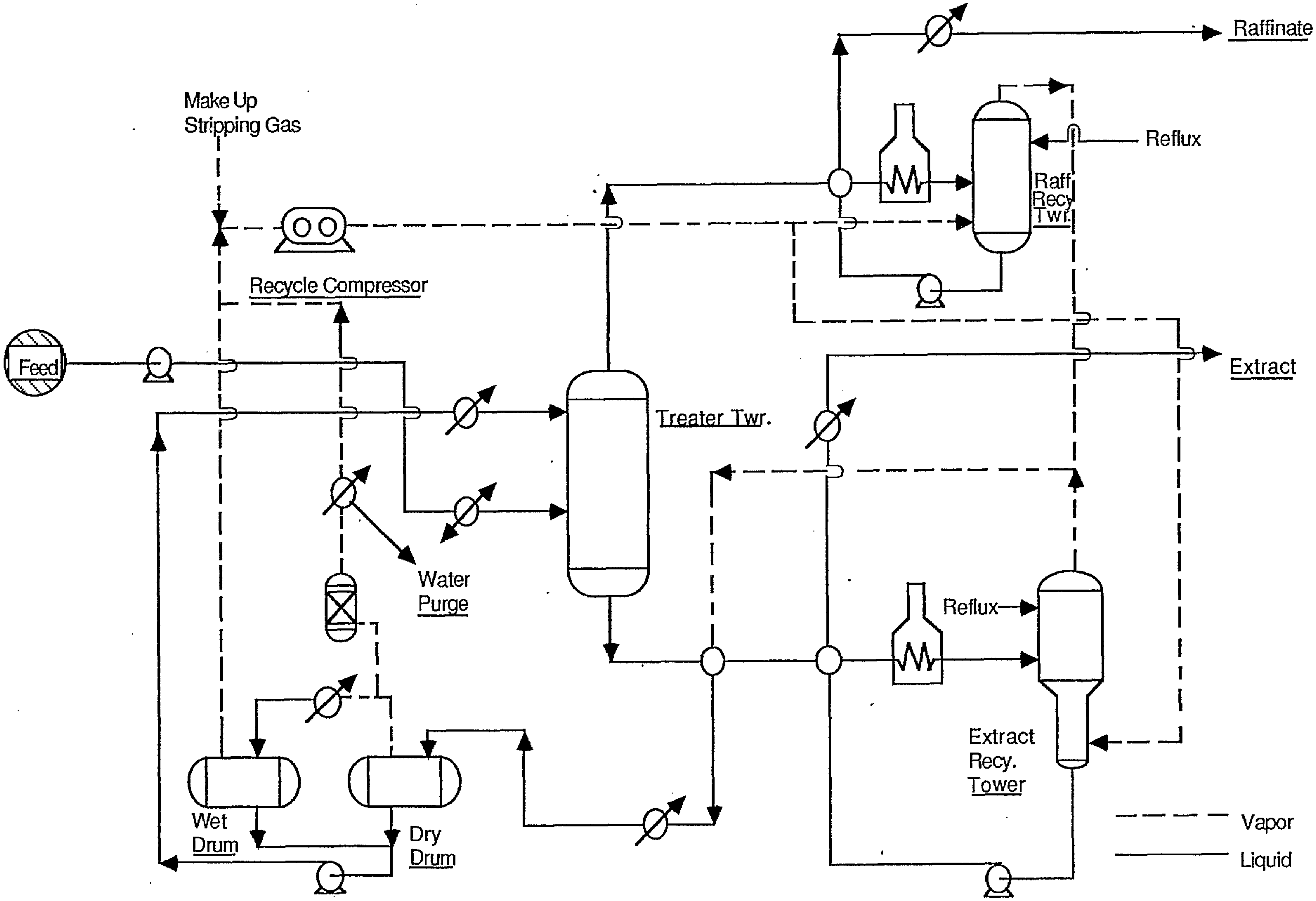

EXHIBIT II

DESIRABLE CHARACTERISTICS FOR NEW SOLVENT

CHARACTERISTIC	IMPLICATION
SELECTIVITY	HIGHER YIELD
BOILING POINT < ∿ 200°C	RECOVERY BY DISTILLATION
LOW HEAT CAPACITY/HEAT OF VAPORIZATION	LOW ENERGY REQUIREMENT
LOW VISCOSITY/HIGH DENSITY	GOOD OIL/SOLVENT SEPARATION
LOW MELTING	EASY HANDLING
NON-TOXIC	ENVIRONMENTALLY SAFE
THERMALLY STABLE	NO RECOVERY LOSSES
NON-REACTING WITH OIL/WATER	"
NO AZEOTROPE WITH OIL/WATER	"
LOW COST/EASY AVAILABILITY	LOW CAPITAL/OPERATING COST
NON-CORROSIVE	"
NO PATENT RESTRICTIONS	FREEDOM TO USE

IMPERIAL OIL LIMITED (B)

DEVELOPING EXPLORATION DRILLING TECHNOLOGY FOR THE BEAUFORT SEA

For more than a decade, consortia led by three of the major Canadian oil companies--Esso, Gulf and Dome Petroleum--had been drilling for oil and gas deposits in the inhospitable Canadian Beaufort Sea. Commercial gas reserves had been discovered, but whether sufficient oil deposits exist is less certain, although recent discoveries lent some encouragement. The industry view was that, in order for the Beaufort Sea to become a commercial oilfield, one billion barrels of oil would have to be present, with 400 million barrels in one structure, to serve as a "stand-alone" project needed as the trigger for development. If such deposits were discovered, a pipeline to southern markets would become an economic reality.

Prospects looked promising by the middle of 1985. So much so that Arden Haynes, Chairman and Chief Executive Officer of Imperial Oil Limited, Esso's parent, told his company's shareholders "we are hopeful of commercial oil production [in the Beaufort Sea], if only on a small scale, perhaps in the 1990s"[1] at the spring annual meeting in Toronto.

These remarks were made possible because of encouraging oil discoveries in late 1984 and early 1985. Esso's Nipterk L-19 and Tuk J-29 exploratory wells showed significant amounts of oil. These discoveries followed hard on

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[1]Dunnery Best, "Recent Finds Ensure Major Oil-Producing Status for Beaufort," The Financial Post, June 15, 1985, p. 35.

This case was prepared by Professors Philip Rosson and Michael Martin of Dalhousie University as a basis for class discussion rather than to illustrate effective or ineffective handling of an administrative situation. The authors gratefully acknowledge the financial support of the Federal Department of Regional Industrial Expansion, Office of Industrial Innovation in the development of this case.

heels of a major Gulf discovery at Amauligak. With these findings, both companies were engaged in delineation drilling, a method employed to more precisely assess the size of the deposits discovered.

These activities engendered considerable excitement, and meant that a profitable payback on the sizeable exploration investments was now a stronger possibility.

Company Background

Esso Resources Canada Limited of Calgary, Alberta is the wholly owned exploration and production subsidiary of Imperial Oil, a company that provides more than 10 percent of Canada's oil and holds vast reserves of natural gas, oil, coal and uranium. Imperial's 1984 sales were $8.6 billion, with profits of $533 million. Imperial itself is 69.6 percent owned by the Exxon Corporation of the United States, the world's largest oil company (with 1984 sales of $91 billion, a net income of $5.5 billion and operations in nearly 100 countries).

Founded in London, Ontario in 1880, Imperial pumped its first oil in southwestern Ontario, then later from wells in the Prairies. Imperial grew quickly and, needing money to expand further and in the absence of interest in Canada and England, turned to the U.S. Standard Oil company (later to become Exxon) for investment capital. In 1898, and for $15 million, Standard Oil bought a majority interest in Imperial.

By 1946, Canada's oil refineries were highly dependent on imports and on oil from the rapidly depleting Turner Valley field lying to the south of Calgary. A new oil field was urgently needed by the Canadian industry. In February 1947, Imperial struck a major new field.

> "After spending $23 million in 20 years, surveying more than 20 million acres in Alberta and Saskatchewan and drilling 133 consecutive dry holes, it hit the proverbial gusher at Leduc, southwest of Edmonton. It was a 200-million-barrel bonanza discovered in secretive Devonian reef limestone fields that gave no

hint of their existence above ground".[2]

Further discoveries were made by Imperial in Alberta through the 1950's and 1960's. As a result Imperial and Alberta prospered together.

Imperial's exploration activities were considerably broadened in the mid-1960's as (yet again) the company saw Albertan production levelling off in the 1970's. These activities were directed in four new areas: the Cold Lake tar sands on the Alberta/Saskatchewan border, the Beaufort Sea/MacKenzie Delta, the Arctic islands, and the East (Atlantic) coast (see Exhibit 1). These were all speculative investments made in the hope that one or more would produce the oil the company forecasted it would need 10 years later. The Beaufort Sea/MacKenzie Delta expansion programme was especially challenging, particularly in its development of an exploration drilling technology for the Beaufort Sea.

Exploration in the Beaufort Sea/MacKenzie Delta

The deltas of a number of the world's major river systems have shown themselves to be rich in hydrocarbons, with substantial oil fields currently being worked in the Gulf of Mexico (the Mississippi River), the Persian Gulf (Tigris and Euphrates), and Lake Maracaibo, Venezuela (Orinoco). Geological surveys suggested that the MacKenzie River Delta and offshore Beaufort Sea might also yield substantial hydrocarbons, for underlying this area are the same tertiary sediments in which 65 percent of the world's oil and gas is found. This prompted Esso's[3] interest in the area in the mid-1960's for which it was granted exploration leases in the MacKenzie Delta lands and out to the 60-foot water line in the Beaufort Sea by the Canadian federal government.

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[2] "The Age of Imperialism Comes to an End", Canadian Business, August 1982, pp. 61-71.

[3] Hereafter we use the proper noun Esso when referring to Esso Resources Canada Limited, the exploration and production arm of Imperial Oil.

Esso developed its exploration programme in the Beaufort Sea/MacKenzie Delta in two stages. Recognizing that onshore exploration would be less difficult than that offshore, the first stage saw activities move north in the MacKenzie Valley towards the Delta. Esso had previous experience of working in cold weather areas, having run a production operation and small refinery at Norman Wells in the Northwest Territories (some 500 miles southeast of the Beaufort Sea) since 1932. As exploration moved north, the firm's researchers were called upon to assist in several problem areas. These included: attempts to improve radio communications, studies of the tundra with a view to minimizing damage from large vehicles and possible oil-spills, assessing the effect of barge traffic on bird life (there being a bird sanctuary in the Delta area), and human survival in the Artic. Wells were drilled from 1964 onwards resulting in the discovery of large commercial gas fields, but the oil deposits were small and while not likely of commercial quantity, they did however offer promise of further deposits off-shore. Over time, Esso grew confident that it could operate successfully in the Delta area, so attention then shifted to the harsher offshore.

The Beaufort Sea exploration programme was important to Esso because two-thirds of the acreage for which it held leases lay offshore. Timing was crucial as well. Under the terms of the leases gained from the government, exploration had to be completed by the late 1970's, otherwise the terms would have to be re-negotiated or the acreages surrendered. Given the importance of the offshore area and the time-limits involved, Esso management set in motion a programme to evaluate the attractiveness of its offshore acreages. Following seismic surveys, offshore petroleum development starts with exploratory drilling, followed (if economical) by production of oil and gas. In order to carry out exploratory drilling, a stable platform is required.

Drilling can last from about 30 to 160 days depending on the well depth, drilling factors and whether any testing for hydrocarbons is conducted.

Jim Lee, formerly Production Development Manager in the Production Department remembered some of the early steps in this programme as follows:

> "We started to look at various systems that would allow us to explore offshore. All of the offshore oil exploration that had been done to that time had been with jack-up rigs and barge-mounted rigs...they probably would have worked in the Beaufort, but the season up there was only 60 days. So it looked as though it would take two or three years to drill a well by that method, which would be very costly. As a result we started to look at other systems that could deal with the environment. We knew that when people built bridges in areas that had a lot of ice, the bridge piers tended to be of a conical shape, so we dreamt up some conical drilling systems made out of steel...and again, it seemed it very possibly would work. We also knew that in Holland and other places a lot of very effective earth dykes and causeways had been built".

> "So we had these three general approaches, but we still didn't know much about the environment. This meant we had to go and collect some engineering data; we made borings of the ocean floor to determine what combinations of sand, silt and clay existed. As well, we got the drilling people to look at how big a structure they needed. This meant we began to get some idea of the size of rig necessary and of the pressure we could put on the ocean floor. We also collected wind data from weather stations we established, and wave height data from buoys employed in the area. This was all pretty straightforward but we still didn't know how the ice would move, and this scared people more than anything else. As a result we started our ice research, at Eagle Lake [east of Calgary], in our Calgary ice basin, and in the Beaufort itself".

These comments encapsulate some of the work done by Esso researchers in the late 1960's and early 1970's, which is now described in more detail.

Developing Exploration Drilling Technology

When exploration leases were granted in the mid-1960's, neither Esso nor the relevant government agencies knew very much about the physical environment of the Beaufort Sea. Even less was known about the suitability of various technologies for exploration drilling. As a result, a Frontier Offshore Section (FOS) was established within Esso's Production Department, first to develop and examine various exploration concepts for the Beaufort and second to assess the development systems that might be used if exploration proved successful. As well, in the words of one executive, FOS was to act as a "conscience" of the operating people.

> "We were out in the middle of nowhere, nobody had been there before. There were all kinds of legitimate questions that could be asked and needed to be asked, not only for our satisfaction but also for society's satisfaction."

This role as "conscience" required a great deal of interfacing work between the FOS and the various Esso groups involved --operations, production research and numerous external consultants.

The FOS played a key planning and research sponsoring role during the decade that Esso expanded its operations in the Beaufort. In much of what follows, reference will be made to either the work of the FOS in developing exploratory drilling concepts, or to the studies carried out by the Production Research Group. Although it may appear that Esso's knowledge developed because of the separate actions of these two groups, in reality, the two were closely intertwined. The exploration drilling technology was developed through a programme involving many people and skills, ranging over a considerable number of years.

Exploratory Drilling Concepts

The key matter that Esso had to address in the Beaufort was the thick, moving ice that covered the sea except for the brief open water period between late July and early October. These severe operating conditions meant that technology from other offshore areas could not be employed. For example, although drilling had taken place in the Cook

Inlet of Alaska for a number of years, even here-- where oil and gas was found in the mid-1960's--ice was only a factor for three or four months of each year.

Although Esso's offshore leases lay between the shore and the 60-foot water depth line, there was some feeling that in the future the company might explore in deeper water. Because of this, a wide range of possible drilling systems were considered. By the end of 1974, some 14 different drilling concepts under three major headings had been thoroughly examined by the FOS. The headings were: islands, fixed bottom founded structures, and floating equipment. Island technology was, in some respects, the simplest and most natural alternative, involving the creation of an island from which to drill. A number of different methods for creating islands were conceived. (See Exhibit 2 for a verbal description and diagram of each alternative.) The fixed bottom founded structures examined by the Frontier Offshore Section used Exxon's Cook Inlet experience as a departure point for the Beaufort, whereas a variety of floating equipment was conceived of as capable of operating in the Beaufort.

The FOS provided detailed information for each alternative: 1) a pictoral representation (sketch, engineering drawing or photograph), 2) an assessment of the status of the technology embodied in the concept, as well its advantages and disadvantages, 3) drilling cost calculations, and 4) design and construction timing. Comparisons of the 14 concepts on system development costs and timing are provided below.

Two critical factors in assessing the drilling concepts were the ability of the technology to operate in different ice conditions and at varying water depths. Exhibit 3 illustrates this point, and Exhibit 4 provides more detailed information.

From Drilling Concept to Operational System: Costs and Timing

Drilling Concept	Approximate Cost	Readiness Time
Island Technology		
1. Dredged islands	already developed	in operation
2. Retained islands	≤ $200 m	≤ 2 yrs.
3. Ice islands	≤ $200 m	≤ 2 yrs.
4. Blast-formed islands	≤ $200 m	≤ 2 yrs.
Fixed Bottom Structures		
5. Monopod	≈ $ 500 m	3-4 yrs.
6. Cone	up to $ 1 b (depending on depth)	3-4 yrs.
7. Monocone	> $ 1 b (depending on depth)	3-4 yrs.
8. Posted drill barge	≤ $200 m	≤ 2 yrs.
Floating Equipment		
9. Air cushion rig	≈ $500 m	3-4 yrs.
10. Conventional drillship	already developed	3-4 yrs.
11. Ice breaking drillship	up to $ 1 b	3-4 yrs.
12. Arctic drill barge		
13. Ice cutter	$500 m-$1 b	5+ yrs.
14. Floating ice platform	---- not suitable for Beaufort Sea ---	

Research on the Physical Environment

As the FOS began its work on drilling concepts, so did research by the (then) Production Research Group on the physical environment of the Beaufort Sea. This would enable Esso to understand better the operating constraints they would face and, in so doing, guide the establishment of the design criteria for the various drilling system alternatives under consideration. Relatively little was known about the Beaufort Sea in the mid-1960's except that it was an extremely hostile environment in which to work. As Vern Larson, Manager of Esso's Research Department, recalled:

> "the properties of ice were not known when we started to work in the Beaufort--we knew that any drilling structure had to withstand ice forces and we knew that the ice moved--but we didn't know how fast or from what direction."

Ice - Structure Interaction Research

The interaction between Beaufort Sea ice and likely future drilling structures provided the focus for the ice research which began in the Production Research Division (PRD) in 1969. Structures had been built to stand up satisfactorily to ice forces in various parts of the world, but the severe ice conditions of the Beaufort Sea presented a unique challenge.

Because a monopod drilling structure (with its narrow cylindrical column) had been used very successfully in the Cook Inlet, the earliest studies of PRD investigated the action of an ice-sheet against a vertical pile-type structure. This research was necessary in view of the wide variation in recommended ice pressures found in the engineering literature. To address this problem Esso conducted tests in both the Beaufort and at Eagle Lake, an irrigation lake east of Calgary, pushing piles up to five feet wide through the ice. Data were collected between 1970 and 1973 on various relationships including: pile width, ice thickness and the crushing strength of ice, the effect of pile shape, and pile-ice bonding.

While these tests were in progress, work also started on conical structures. The main reason for investigating a conical shaped structure was the knowledge that ice forces could be reduced by causing bending rather than crushing failure--see Exhibit 5. (Conical shaped bridge piers had been employed for many years in, for example, the St. Lawrence River.) Following theoretical work and small scale modelling, a large open air ice test basin was constructed behind Esso's PRD facility in Calgary. This 180 ft. long by 100 ft. wide basin is the largest in the world, and was built to provide the opportunity for experimentation on a larger scale. Structures for testing were instrumented to measure horizontal and vertical forces, and the ice pulled into the structure by a boom and towing system with a 100 ton capacity. Early tests were of a 45° steel conical structure with a 10ft. diameter at the ice level. Ice sheets up to 27 inches thick were tested against it.

Ice Conditions in the Beaufort Sea

This ice-structure interaction research required that Esso learn more about ice conditions in the Beaufort. A survey of the Beaufort ice was conducted in 1969, data being collected on ice thickness, ice salinity and temperature (since it was known that these affect strength), and ice movement. Over the next few years, a considerable amount of knowledge was amassed. What the PRD researchers learned about Beaufort ice conditions is shown in Exhibit 6--a map of the three ice-zones in the Beaufort Sea, and Exhibit 7--a typical cross-section through the ice-zones.

Landfast ice includes new ice that forms from October onward and is anchored to the shore. By January, the landfast zone extends to the 60 to 80 foot water line. Inshore, this ice generally grows to a maximum thickness of

6 feet and has a smooth surface. Further offshore, however, first-year ridges are found. These are caused by wind action on ice that is not landfast in November and December. This ice, continually broken and ridged by the wind, is heavily ridged when it does join the landfast ice late in the year. Depending on the amount of ice movement and water depth, some of these ridges ground on the sea bed, giving the ice some stability since it remains in this position for the rest of the winter. Landfast ice is relatively stable but wind and thermal stress can deform the ice and cause movements of several feet per day. Movements increase with water depth or distance from shore.

Offshore--further north and west--is the polar pack which is predominantly made up of multi-year ice; the pack is constantly moving in a clockwise direction. The multi-year ice of the polar pack averages 15-20 feet in thickness, but extreme thicknesses of 100 feet in occasional ridges, hummocks and ice islands are found. Between the landfast and polar zones are the transition and shear zones, often characterized by an open lead (or exposed water).

Other Environmental Conditions in the Beaufort Sea

Another aspect of the Esso research concerned weather and soil information. Under the heading of weather--wind, wave and current data were required. Furthermore, Esso had to be able to forecast weather in the Beaufort. The company had good onshore wind data from weather stations it established in the area, and had employed wave-rider buoys to record wave heights. This data had, in turn, been used to produce a hindcast[4] for 15 to

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[4]A hindcast is a prediction of the probability of various winds and waves occuring using historical data as its basis.

20 year recurrence probabilities of winds and waves. In the sea current and weather forecasting areas, slower progress had been made.

Regarding soils, shallow water seismic surveys had been made, as well as core samples from different offshore site investigations to determine what foundation might exist for a drilling platform. The foundation soils were found to vary from silts and clays in the west to silty sands in the east. Further deeper water (30 to 60 feet) soil samples were planned, along with studies to determine sand/gravel reserves in the area.

Moving Ahead with Exploration

PRD researchers were working on a number of fronts in 1972. The monopod and conical structure research was progressing, aided by increasing amounts of data and insight into Beaufort conditions. The FOS had identified the 14 drilling alternatives cited earlier and was investigating each in detail. There was an impetus to start work on an actual drilling platform, however, and so in the summer of 1972, Esso began building its first platform at a sheltered location in the Beaufort Sea.

Dredged Islands

The platform was to be a dredged island in 10 feet of water, as FOS's initial assessment of this drilling platform concept was positive. The fact that this technology was proven and seemed relatively simple, plus the availability of sand and dredging equipment suggested that, at the very least, this was a good way to start offshore exploration. First, however, Esso management wanted to assess the impact of ice forces on such a structure in the "field". So it was decided to build the island over two seasons. In the first season, the island would be constructed to be above the water. Over the ensuing winter, the effect of ice on the island was to be examined. If this proved to be tolerable, construction was to be completed the next summer so that drilling might then proceed. According to Jim Lee, by the end of that first winter:

> "it was obvious that the island [Immerk B-48] controlled the ice rather than the ice controlling the island--you could see ice rubble fields forming around it--but the island was stable".

This was a very heartening finding because there were some concerns that ice forces could be strong enough to shear away an island and, should the island be producing oil, a catastophic failure to operations and extreme danger to the biological environment could result.

Following the first winter's experience at Immerk (see Exhibit 8), it was accepted that dredged islands were an acceptable way to start drilling. As a result, the island was completed and a well drilled in the winter of 1973-74.

> "From that we continued to try and fine-tune the design criteria, better understand the weather and look at systems which might be more cost- effective. We'd really overcome, I think, the major research hurdle with that first island ... there's been a fine-tuning of the drilling system ever since. And there's been some major strides in that fine-tuning ... there's no doubt about that!"

--Jim Lee again.

Research on other drilling structures did not cease at this point. The monopod concept was looking less favourable as it required the passing ice to fail in its <u>strongest</u> (or crushing) mode. However, work proceeded on the conical structure since it caused the ice to fail in the much <u>weaker</u> flexural (or bending) mode. The basic ice and environmental research continued as well, aided now by data from Immerk.

Ice action on the dredged island proved to be at its height in the fall, prior to the ice becoming landfast. However, this was also the time of year when the landfast ice was at its thinnest. The result was that as the ice moved into contact with the island, rather than riding up the island and endangering the working surface, it bent and cracked. Successive ice actions led to the formation of ice piles (called rubble piles) on the perimeter of the island (see Exhibit 9). Again though, complacency was avoided, since it was realized that islands in more exposed locations might well be susceptible to ice ride-up by polar ice.

Research activity heightened through this period. With momentum as well as experience building-up, FOS found itself interacting even more closely with other groups. Now it began to play a true interfacing role between exploration, operations and research--learning how the island was performing, what new wells were to be drilled and what gaps in knowledge existed. As the Section's Head described it "we were moving backwards and forwards all the time".

Ten more dredged islands were built by Esso between 1973 and 1976 (Exhibit 9). Most were built in the summer by dredging sand from the seafloor, but two were constructed in winter by trucking gravel over the ice. Island construction methods improved as experience grew. Although the initial concerns about islands centered on ice forces in the winter, ironically ocean action in the summer proved to be a major menace.

Two problems were encountered. First, because of the long construction time, islands tended to break clear of the water toward the end of the summer; a time when storm activity was at its peak. Some Esso researchers were surprised at how much sand could be removed from the island by sea action during such a storm. The second problem was an everyday one. Normal wave action and ocean currents eroded unprotected islands considerably. The company's initial response to this was to use sandbags to shield the steep island slopes from these storm and ocean forces (see Exhibit 10).

Another difficulty concerned island fill material. A small number of islands had to be rebuilt two or three times because too much silt in the dredged materials led to rapid erosion. At this point, Esso realized that its operations had progressed beyond its research, and so undertook studies to appreciate better the interaction of sand and silt--how they would drain and, therefore, consolidate. Furthermore, this experience with silt made it clear that a better job had to be done in locating suitable sand deposits for future construction purposes.

A further area where research proved necessary was dredging. Pressure due to floating, wind, or current driven ice, had made it impossible for the dredging line (a wide tube carrying the dredged materials between dredging vessel and island) to stay on location on a number of occasions, and construction interruptions occurred. This again reflected unfamiliarity with the Beaufort environment, as did the occasion when a dredging vessel got caught in heavy ice. Management had a number of anxious weeks over this. Fortunately, the situation did not become serious. This incident prompted more effort into improved weather forecasting and better communications, so that changing environmental conditions would be spotted more quickly and operational units made aware of this promptly.

Despite these incidents, the dredged island concept proved to be sound. Esso was able to react to the difficulties it experienced, so that each exploration well was drilled on schedule and within cost estimates developed by the FOS.

Sacrificial Beach Islands

Another approach to dealing with the eroding effect of the ocean on the dredged islands resulted in the development and building of sacrificial beach islands. Beginning with Arnak L-30 in 1976 (see Exhibit 8), a number of these larger islands were constructed, the eroding action of waves on the drilling platform being minimized by the 55 yard sacrificial beach surrounding it (Exhibit 10). Of course, by building larger islands of this kind, more fill material is required. Issungnak is Esso's largest sacrificial island built in

1979. This island was built on the extremity of Esso's offshore acreage in 60 feet of water. Because it employed the sacrificial beach principle in deep water, Issungnak required five million cubic metres of dredged sand to achieve the design of a 980 yard diameter seafloor base (as big as 70 football fields), 270 yards at the water line, and 148 yard diameter working surface 18 feet above the water. Issungnak took two summers to construct and cost $60 million.

Given these fill requirements and costs, as Esso's exploration programme called for drilling in deeper locations, islands with steeper slopes became highly desirable. As well, the company planned to explore in the western part of the Beaufort where suitable fill materials were not available. This would mean transporting sand from as far as 50 miles away, raising island construction costs by as much as 400 percent. Esso clearly needed a new solution to these problems. The answer was the caisson.

The Caisson Retained Island (CRI)

Design work began on the CRI back in 1974, when the FOS recognized the need for contingency planning to deal with the exploration and fill availability problems that might arise when drilling began in deeper water. Caissons (or floating oblong boxes) are not a new idea, having been used, for example, by the Allied forces in the Normandy invasion in June 1944. They are new to the oil industry, however.

Esso embarked on a $2 million caisson engineering programme in 1975. It looked at various designs over a three year period, making considerable use of the Calgary PRD ice basin. In its final form, the CRI design employed eight 40 foot high caissons each weighing 1000 tonnes, and linked together through 16 stressing cables so that they formed a structure 386 feet across. This octagonal caisson (affectionately referred to as the "giant doughnut") is water-ballasted down onto a dredged subsea platform (or "berm"), built to within 30 feet of the sea surface (see Exhibit 11). Dredges would then fill the "hole in the doughnut" to create a working surface for drilling the well and supporting the auxiliary equipment, exploration team camp etc. Cranes would then lower equipment and facilities onto the island. The CRI required only 20 percent of the sand of a sacrificial beach island and, furthermore, would be re-useable. After drilling was completed at one location, the eight caissons could be refloated, split into two sets of four and towed by tugs to a new drilling location.

By 1979, activity on the caisson stepped up. Orders were placed for the steel required and arrangements made for tug and crane construction and operation. A contract was placed with a shipyard in 1981, and building of the Caisson began the next year. Six months later in July 1982, the caisson segments were floated out of drydock and assembled for testing, following which they were loaded on submersible barges and set out for the Artic. Over the winter of 1982-83, finishing touches were made to the caisson in the Beaufort. The next summer saw it put in place at Kadluk (see Exhibit 8), where a berm had been built the previous summer. Ten days after the caisson had been ballasted down, sand infilling was completed and the drilling rig was assembled on the CRI.

Drilling operations at Kadluk confirmed the presence of hydrocarbons, and the CRI system performed very well, meeting the expectations of Esso's Production Drilling Manager in ice conditions that were more severe than normal. In July 1984, the Caisson was moved to begin drilling at Amerk, about 60 miles east-northeast of Kadluk, where it was to enable drilling to take place through the winter of 1984-85.

Continuing Research Activities

While drilling was taking place on a variety of drilling platforms--dredged, sacrificial beach and CRI--further research advances were made.

One significant discovery in the latter half of the 1970's was that average ice pressure on a wide structure was considerably less than that on a narrow structure. Whereas the early research had shown that there was a width effect on the crushing action of ice, insufficient data were available to be confident about this. With the development of dredged islands, however, it became clear that the width of the structure did have an influence on ice loads. The explanation for this became clear. Observation of ice around the early islands showed that it did not fail simultaneously all-around them. Rather, at any one time, different areas of the surrounding ice were in varying stages of failure. This led to the belief that the wider the structure, the more areas of failing ice and , hence, the lower the load per unit width on the structure itself. This was a significant finding because, if borne out, it meant that future islands would not have to be built to resist the ice loads designed into the first islands. This, of course, translated into lower construction costs and faster island completion. Further experimentation reinforced the width-effect idea, and the development of a stochastic model--based on this work--allowed predictions of ice stresses on later artificial islands to be made with greater confidence. Furthermore, the formation of grounded rubble fields around islands served as a buffer, absorbing some ice forces and leading to even less ice loading on the islands.

By the summer of 1984, Esso researchers were looking at sacrificial beach islands afresh. Company engineers felt that narrower sacrificial beach islands might now be possible, because a substantial gravel deposit, recently found in the Beaufort, offered itself as a better construction material than the sand traditionally used. Tests conducted in the Calgary PRD ice/wave basin showed that 22 yard gravel beaches were an acceptable substitute for the proven 55 yard sand beaches, and that moreover, a one-third construction cost saving could result. This research project followed from the one that discovered the gravel deposit.

Another researcher had hypothesized that some gravels Esso had previously discovered in the Beaufort were the remnants of a former shore line or barrier islands. Some smart "detective" work was carried out using seismic surveys and bathymetry maps of the Beaufort, and then the researcher "breathed down the necks" of the operations personnel until his hypothesis was confirmed and the deposit located.

The location of the gravel deposit also prompted another project. This again involved PRD coastal engineers and soil scientists, whose task was to come up with a better solution to the "toe protection" for the CRI. Recognizing the considerable eroding effect of waves on islands, initial plans for the CRI included filling the area adjacent to the join of the caisson and berm. The "toe" of the caisson was protected by a sloping (1 in 10 to 12) sand deposit, 10 feet thick at the caisson and extending out from it about 30 feet (see Exhibit 11). With the discovery of the gravel deposit thought could be given to an alternative arrangement. Another factor also suggested further research. Experiments in the PRD basin showed that all of the erosion took place near the caisson's toe, not 30 feet away.

This point, together with the recently found gravel deposit pushed the engineers to look at using gravel in a smaller area around the toe. Basin testing led to the development of gravel protection, with a 1 in 3 to 5 slope, six feet thick at the caisson and extending out 15 feet. This yielded about a 50 percent saving in material and dredging costs. The smaller area of toe protection made it crucial that the gravel be precisely placed. This was accomplished simply: a dredger was moved up very close to the caisson and which then pumped gravel into the area in question. Surveys after pumping showed the geometry of the toe protection to be as desired. The new form of protection was to be first tried at Amerk over the 1984-85 winter.

Another area of cost-saving the soil scientists were working on concerned island foundations. Soils theory suggested that building an island directly onto the soft sediments of the ocean floor would cause the foundations to fail. Esso had always, as a result, removed the softer upper sediments which have been as deep as 8 metres, and replaced this material with sand, thus providing a much stronger island foundation. However, industry data suggested that no foundation failures were taking place and hence the pressure due to the island would continue to strengthen the foundation as time passed. It was felt that the size of the islands explained this phenomenon, as the material which would normally have failed was totally confined. Subsequent research has borne out this theory, and considerable savings have been realized by eliminating the foundation strengthening operations.

Research and Development Funding

Like any company, Esso had to commit substantial internal funds to the vast job of R&D for the Beaufort. Two other methods through which R&D was financed were: Exxon Mutualized Research, and the Arctic Petroleum Operators' Association.

As a subsidiary of the 69 percent Exxon-owned Imperial Oil, Esso had access to R&D expenditures amounting to some $600 million annually. In addition, Esso defines and carries out its own research according to its needs. Esso frequently receives funding for certain research projects from Exxon and this is called mutualized research. For an Esso research project to be funded under Exxon's "mutualized research" programme, a project had to be of interest to Exxon affiliates around the world, and tended to be in a area where the applicant had some comparative advantage, such as climate, a significant resource, or expertise. Because Exxon had drilling interests in and around Alaska, and in the Northern Europe offshore, the Esso Beaufort research was of some considerable interest to them. Esso's comparative advantage included climate: the Calgary PRD facility was able to "grow" ice in its basin in a way that Houston could not! Calgary was also much nearer to the Arctic than Houston, making field research that much easier particularly with the Production Drilling Operations base and infrastructure in the Canadian Beaufort. For these and other reasons, such as PRD staff skilled in ice mechanics, Esso had made representations to Exxon which had resulted in R&D mutualized funding for some of their work in the Beaufort.

The second source of funding was the Arctic Petroleum Operators' Association (APOA), an organization founded in 1969. Publicity surrounding Esso's first ice strength tests attracted the attention of five other oil companies, all with growing interests in the Arctic. From this nucleus, APOA was formed, a group which was to co-operate in funding the very costly R&D work focusing on exploration and production in the Arctic. Funding arrangements are as follows. APOA projects (eg. landfast ice movement) are operated by individual member companies. Others may participate in the project on a voluntary basis, sharing costs in exchange for the data generated by the research. Non-participants are precluded from access to the research data for a five year period. By 1985 some $58 million of R&D had been conducted under APOA's auspicies.

Technology Transfer: MacKenzie River Production Islands

Esso has produced oil at Norman Wells since 1932. Eighty percent of the oil in this field lies under the four mile-wide MacKenzie River. Oil could be recovered by drilling wells at an angle from onshore, but because of the direction of the fractures in the oil reservoir, it was felt that a low recovery rate was all that could be expected. By drilling vertically and in a tight pattern (i.e. from the river), much more oil could be recovered. This led to research into production islands in the MacKenzie from 1978 on. The PRD researchers involved were able to draw extensively upon their experiences from "thinking" islands for about six years in the Beaufort.

The MacKenzie islands faced somewhat different conditions from those in the Beaufort. The most important factor was that these were to be production as opposed to exploration islands. Whereas the latter were built to be abandoned after exploration (permanently, if no oil was found, or temporarily, if the deposit was sizeable), the river islands would have to be designed for a 20 year or greater operating life in a rapidly-flowing river.

Over a period of years, research activities revealed other differences between the river and Beaufort environments. Water level range was one such difference. The river depth in the planned drilling area ranged from 10 to 25 feet except for one period of the year. At spring break-up, the river level rose to give a depth as great as 62 feet (due to ice jamming of the river) and was full of moving ice. Beaufort islands had to contend with a much smaller change in water level caused by tides and/or storm surge. Another difference concerned building materials--much better sand deposits were found, but more important, gravel and rock (an outcrop of the reservoir limestone) were readily available for construction from local sources. A final difference of some significance, although not research-related, was that because Esso had been operating at Norman Wells for some 60 years, the infrastructure was much better developed there than in the Beaufort. As such, construction would be a somewhat simpler undertaking.

Much of the ice research conducted in the Beaufort proved helpful to the

MacKenzie River research team. Techniques developed to measure ice loadings, and the findings on ice ride-up and rubble fields was applicable in the river environment. Construction work on six islands began in the summer of 1982 and was completed three years later. Because of the availability of rock in the area, the islands employed very steep sides. Essentially, the islands are composed of rock rings, hydraulically infilled with sand and gravel dredged from the river bottom, so that they stand 6 feet higher than the highest river level ever recorded.

The islands very successfully dealt with the spring 1984 and 1985 ice break-ups. A reconnaissance team monitored the break-ups very closely, making aerial inspections of the river on at least a daily basis, and from as far as 180 miles upriver from the islands. As break-up neared Norman Wells, monitoring became a day and night activity involving aerial photography, time-lapse cameras on shore and the transmission of measurements from island-located instruments. The islands behaved as predicted in what was assessed to have been a mild, slow break-up in 1984 and a third worst on record break-up in 1985. The monitoring effort was a government requirement prior to production start-up, but also reflected Esso's cautious approach when human and environmental safety was at stake.

The MacKenzie River research was to continue. Very little detailed information had been available on major ice-covered rivers until a few years ago. As was the case in the Beaufort, considerable advances in both applied and pure scientific knowledge would result from Esso's research activities in the Arctic.

The Future

Exploration plans in 1984/85 and 1985/86 involved drilling six new wells: three sacrificial beach islands, two CRIs and two onshore. One of the sacrificial beach islands was used to conduct delineation drilling in the Adgo field, where Esso drilled three wells between 1973 and 1975 and made its first significant offshore oil and gas discovery. The Adgo island and well was to be cost-shared with Trillium Exploration Corporation, a company two-thirds owned by the Ontario Energy Corporation. This approach to exploration had become the modus operandi since the 1980 National Energy Programme (NEP). This legislation sought further to "Canadianize" the petroleum industry through, among other things, only permitting predominantly Canadian owned companies to receive the maximum "Petroleum Incentive Programme" (PIP) grants. These grants covered up to 80 percent of exploration costs. In response to this move, Esso (amongst others) had developed a consortium approach to their Beaufort operation which involved a "Beaufort Exploration Agreement" with the Federal government, whereby other firms would "farm in" (or join) so that the financial advantage of the Canadian ownership criterion of the federal government PIP grant was met, while ending up with close to the NEP-required 50 percent Canadian ownership level prior to applying for a production development permit.

Artificial island exploration technology had worked well for Esso. A large number of islands had been constructed over a period of more than 10 years, and the only problem was when a sacrificial beach island--designed for a 14 hour storm had to endure a 50 hour storm in October 1985. Even there, the island was "repaired" and back in operation in two months. This was partly due to the cautious approach developed--islands were designed to be safe. Of course, what constituted a "safe" island changed over the years, as research showed that ice forces on wide structures were much less than was initially envisaged. However, the prospect of an unusually bad year for ice or storms was always real in the uncertain ocean environment. Although Esso had 10 or more years of data on many Beaufort Sea phenomena, nobody could be absolutely certain whether the 15 or 25 year ice or storm had been experienced during this period. This fact kept company researchers "on their toes" and meant that even though certain aspects of Beaufort research (eg. basic ice research) had been wound down, others (eg. weather and ocean data) still had a high priority.

The FOS had been disbanded by 1984. Once the work on drilling concepts had been completed (which involved considerable interfacing during the early work on the alternative approaches adopted coupled with the assessment of Beaufort development systems) there existed less need for such a group. Drilling from islands was now almost a commonplace operations activity for Esso. All now depended on finding more oil and gas.

Esso's activities over the next two seasons would be important. The company had made one offshore discovery in about 60 to 65 feet of water, which it believed would permit commercial exploration. If any of the wells drilled in the next two seasons were also successful, a second caisson could be built, not for further exploration but rather for production operations. The most effective type of production structure for a particular location will depend primarily on the water depth and environmental conditions. It could be an island, a caisson or a bottom founded structure.

The future of the Beaufort Sea operations was, however, by no means assured. Even though industry estimates of the potential oil reserves ranged from 6 to 32 billion barrels (compared to 1980 North Sea assessments of 10 to 12 billion barrels), the costs of recovery and transportation would be high. Nevertheless, Esso was optimistic about the future of the Arctic area into which it had put so much effort. Whether exploitation was five, seven, ten or whatever years away, the company's researchers would have little breathing space. As one researcher joked

> "Oh, exploration will probably take another four years, red tape three years, and engineering another two--but the part that will be jammed up is the engineering!"

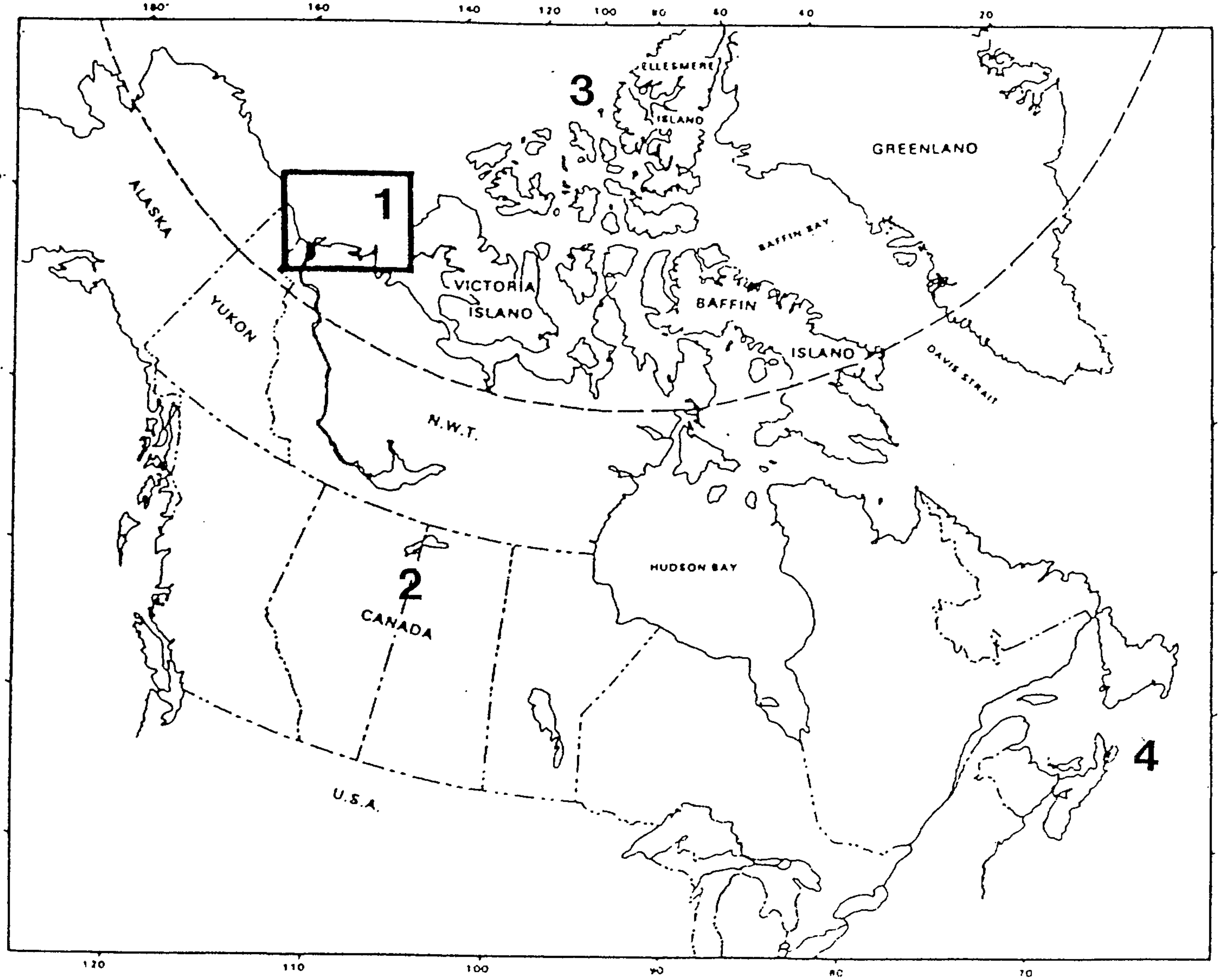
Conclusion

The final word on Esso's development of technology for the Beaufort Sea is best left to Jim Lee, a person intimately involved with the process over a long number of years:

> "We've taken technology that has been developed at other places and applied it to the Arctic environment in an economically smart way. The research that has allowed us to do that has been an understanding of the environment and the necessary design criteria. People have dredged sand for hundreds of years, people have drilled from land-based operations for fifty years--that's nothing. What is 'unique' about the Beaufort is we figured out how we can do that programme in about 90 days, whereas in most areas we have 360 days to do it. We've figured out how to do that programme in a way that provides a lot of flexibility to exploration--because they need that! That's what exploration is about--being able to react to new data. And we've figured out how to do that so that it's cost effective. But there's been no breakthrough technology that has occurred; it has been using existing technology right at the 'leading edge'".

Exhibit 1

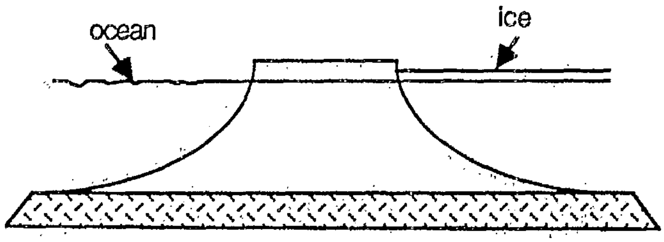
Expansion of Oil Exploration



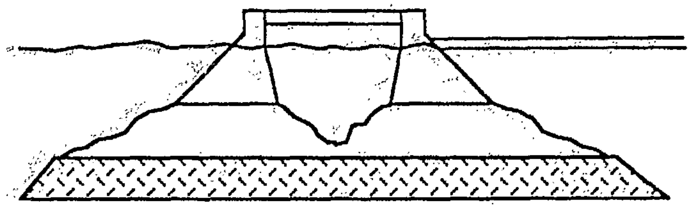
Legend: 1 - Beaufort sea/Mackenzie Delta
2 - Cold Lake tar sands
3 - Arctic islands
4 - Atlantic coast

Exhibit 2
Beaufort Sea Exploration Drilling Concepts*

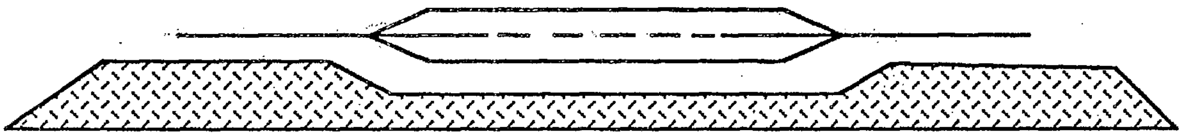
A. Island Technology



1. Dredged islands are built from sand and silt sucked-up from the sea bottom, to operate either in the winter or year-round.



2. Retained islands-- similar to the dredged island but with a concrete or steel retaining wall sitting on top of the sand foundation.



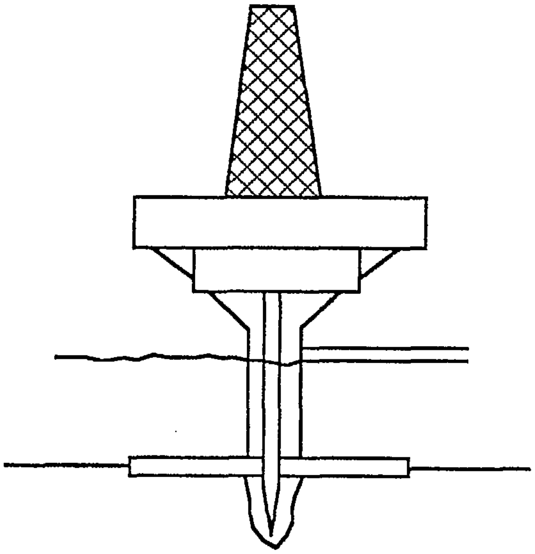
3. Ice islands-- essentially involving the creation of an ice "island" by flooding and freezing a contained area on top of the natural, grounded ice.

4. Blast-formed islands could be made by employing explosives to move earth/fill rather than, for example, dredging.

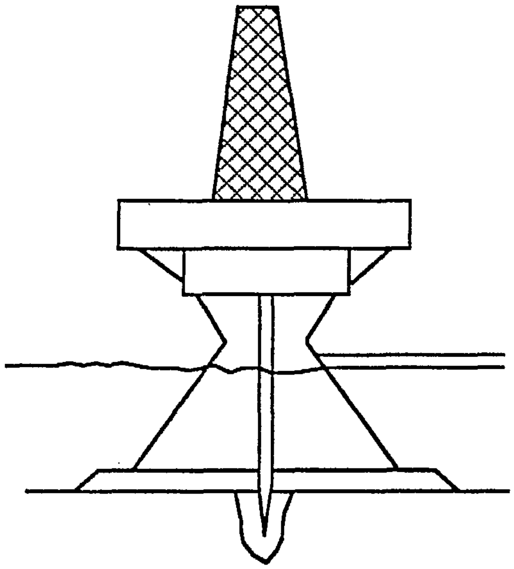
Note: * Drawings not to scale
Source: Adapted from company records

Exhibit 2 (cont'd)

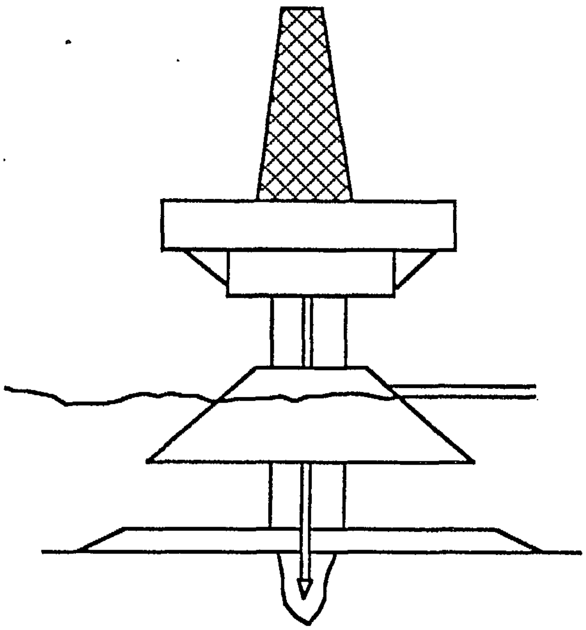
B. Fixed Bottom Founded Structures



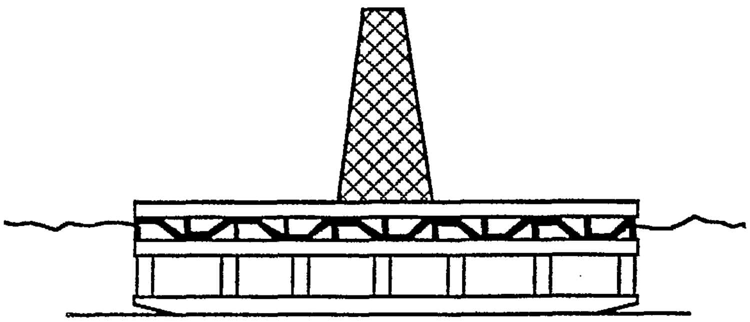
5. The Monopod is a drilling platform which sits above the sea on a cylindrical column connecting it to a huge base fixed to the ocean floor. It could be made of steel or concrete.



6. The Cone is essentially the same as the monopod except that the column supporting the platform is cone shaped. Whereas ice could be expected to be crushed as it moved against the monopod, the cone would induce ice failure by bending.



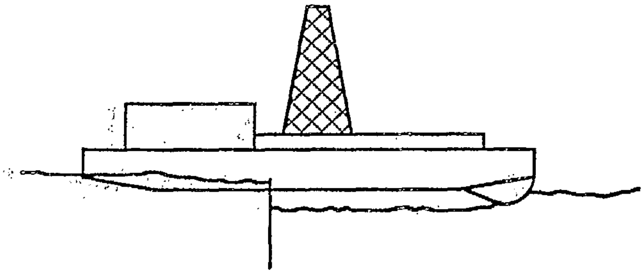
7. The Monocone is a cross between the monopod and the cone. As in the monopod, the drilling platform sits on a central column but again ice failure is caused by bending rather than crushing. Ice would break against a conical colar which would be moved up or down the column. This would enable it to be used at various water depths.



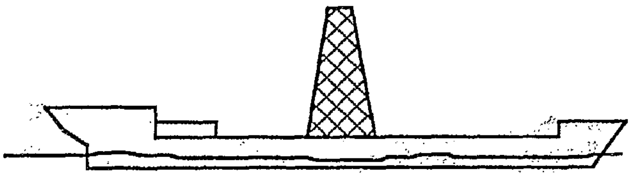
8. The Posted Drilling Barge is different from the previous bottom-fixed structures, drawing not from the Cook Inlet experience but rather from earlier exploration. This technology involves the use of a barge which is ballasted to the sea bottom. The drilling platform is supported on posts attached to the barge.

Exhibit 2 (cont'd)

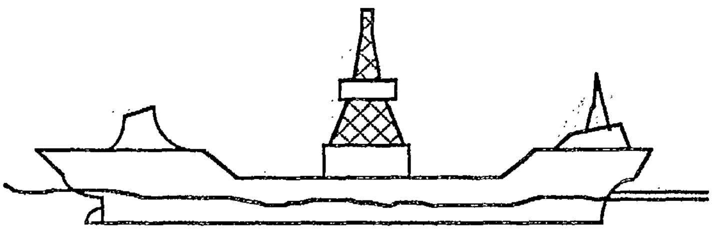
C. Floating Equipment



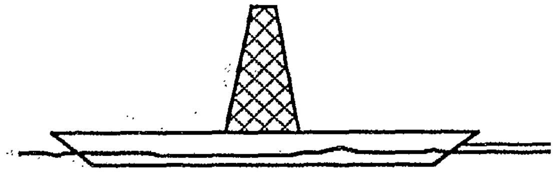
9. The Air Cushion Rig would employ hovercraft principles to maintain its position above the ice or sea-covered drilling site.



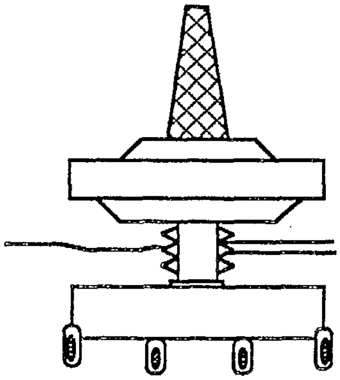
10. The Convential Drillship could only be used in the summer open water period.



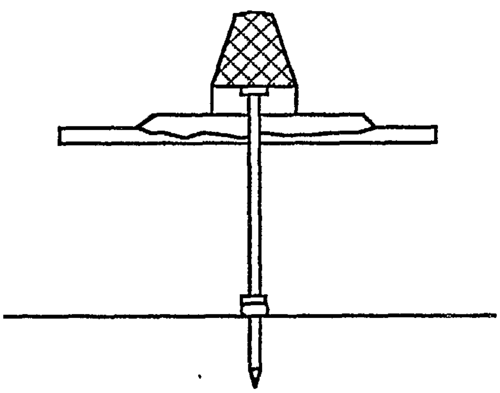
11. The Icebreaking Drillship would be able to drill throughout the year, being strong enough to withstand winter ice forces.



12. The Arctic Drill Barge falls between the above two concepts-- able to work in thin ice with drilling interuptions.



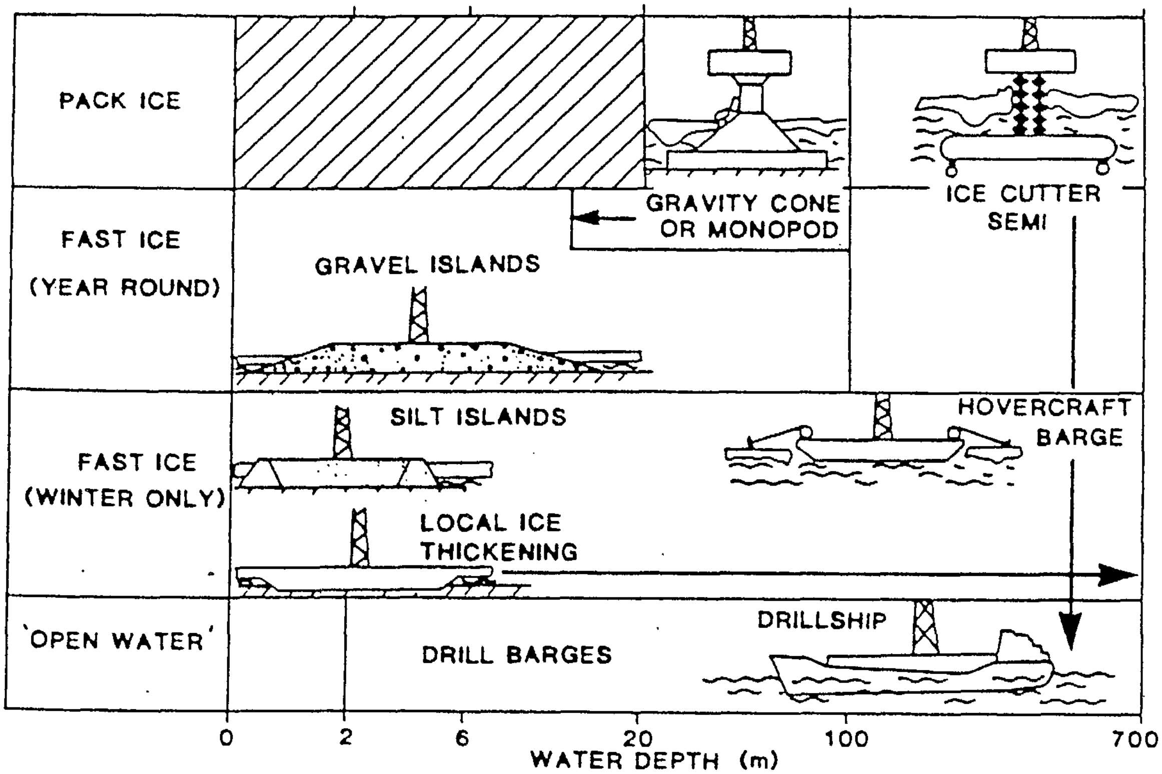
13. The Ice Cutter is similar to the monopod except that a) it is not ballasted to the sea floor byt rather uses underwater thrusters to maintain its drilling position, and b) the central column employs a cutting collar to minimize ice forces on the structure.



14. The Floating Ice platform is the same concept as the previous ice islands except in this case the drilling rig is based on a floating, not grounded base. It was thought that temperatures and ice movements made this concept unsuitable in the Beaufort Sea.

Exhibit 3

Exploratory Drilling Concepts by Ice Zones and Water Depth



Source: Company document

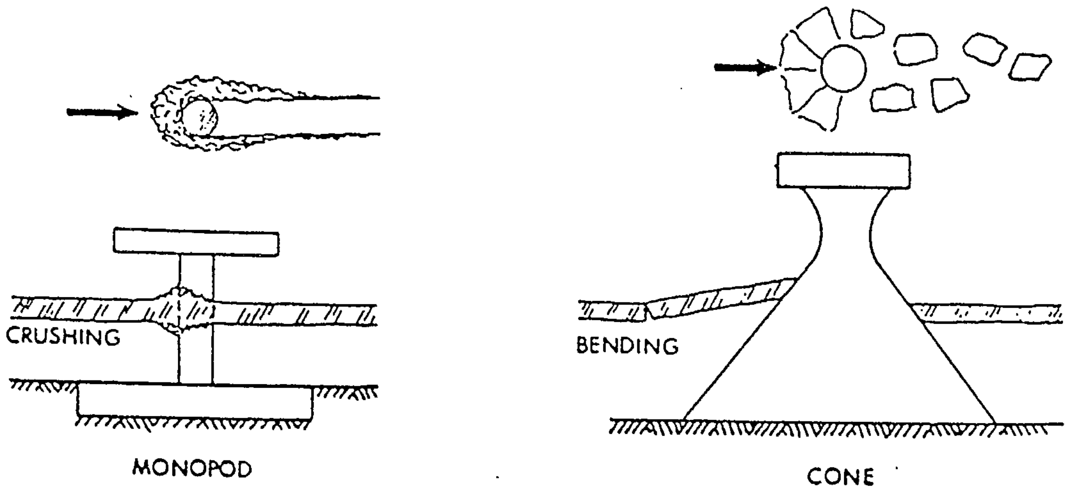
Exhibit 4

Exploratory Drilling Concepts and Operating Constraints

	Water Depth Range (Feet)			Gross Operating Time Estimate (Days)		
	Open water	Ice	Year-round	Open water location	Ice location	Total
Islands						
1. Dredged						
- winter only	--	0-8	--	--	120	120
- year round	--	--	0-40	year round		365
2. Retained	--	--	15-40	year round		365
3. Ice	--	0-8	--	--	95	95
4. Blast-formed	--	--	0-100	year round		365
Fixed Bottom Founded structures						
5. Monopod						
- steel	15-40	15-60	--	80	285	365
- concrete	30-40	30-70	--	80	285	365
6. Cone						
- 70 feet	--	--	35-70	80	285	365
- 135 feet	--	--	46-135	80	285	365
7. Monocone						
- 70 feet	--	--	33-70	80	285	365
- 135 feet	--	--	40-135	80	285	365
- 200 feet	--	--	40-200	80	285	365
8. Posted drill barge	6-15	--	--	90	--	90
Floating equipment						
9. Air cushion rig	40-60	14-40	--	87	175	262
10. Conventional drillship	60-600+	--	--	70	--	70
11. Ice Breaking drillship	50-600+	60-600+	--	80	120	200
12. Arctic drill barge	60-600	--	--	100	--	100
13. Ice cutter	--	--	130-600+	year round		365
14. Floating ice platform		Not suitable for Beaufort Sea				

Exhibit 5

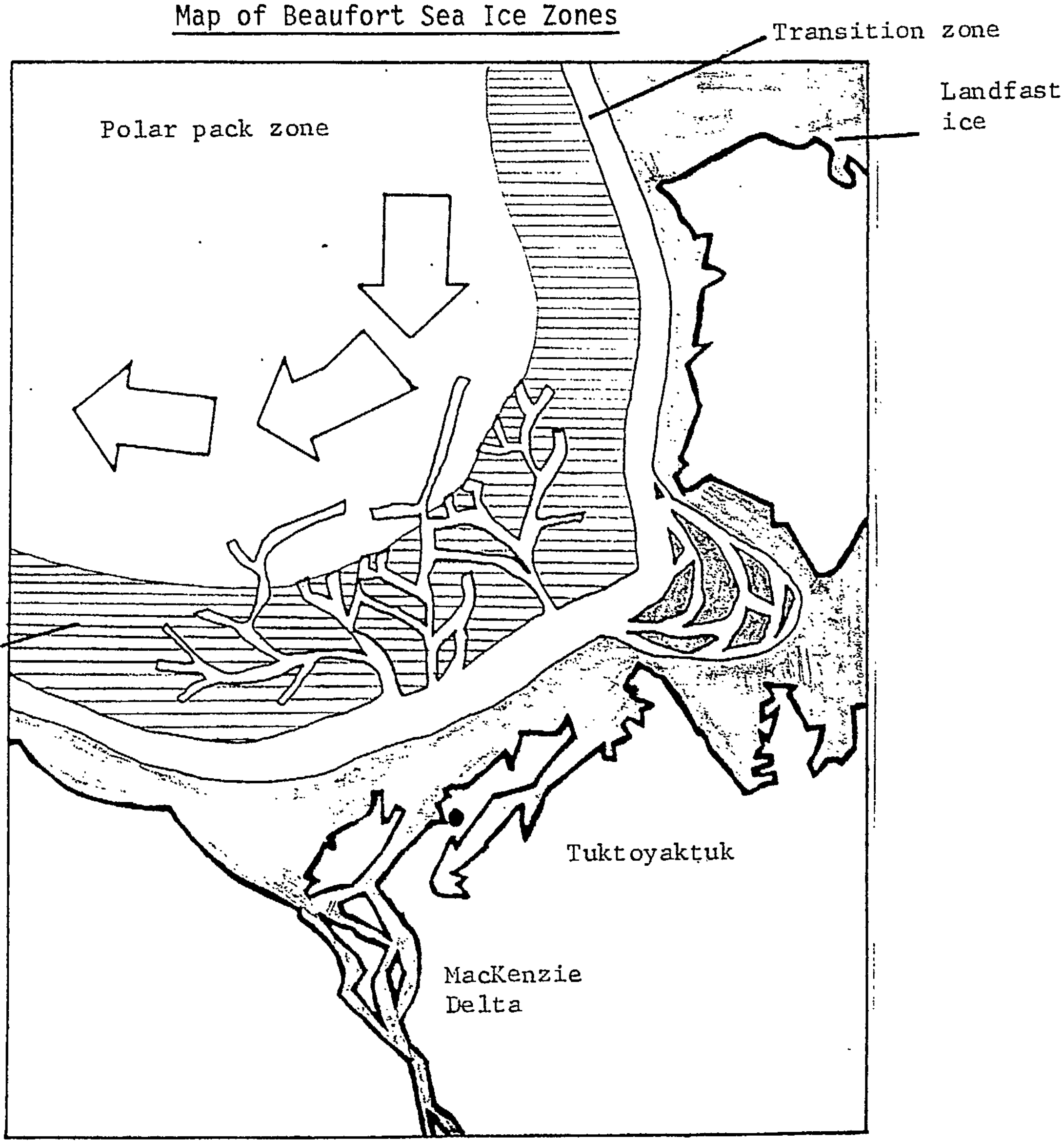
Ice Failure by Crushing and Bending



Source: Company document

Exhibit 6

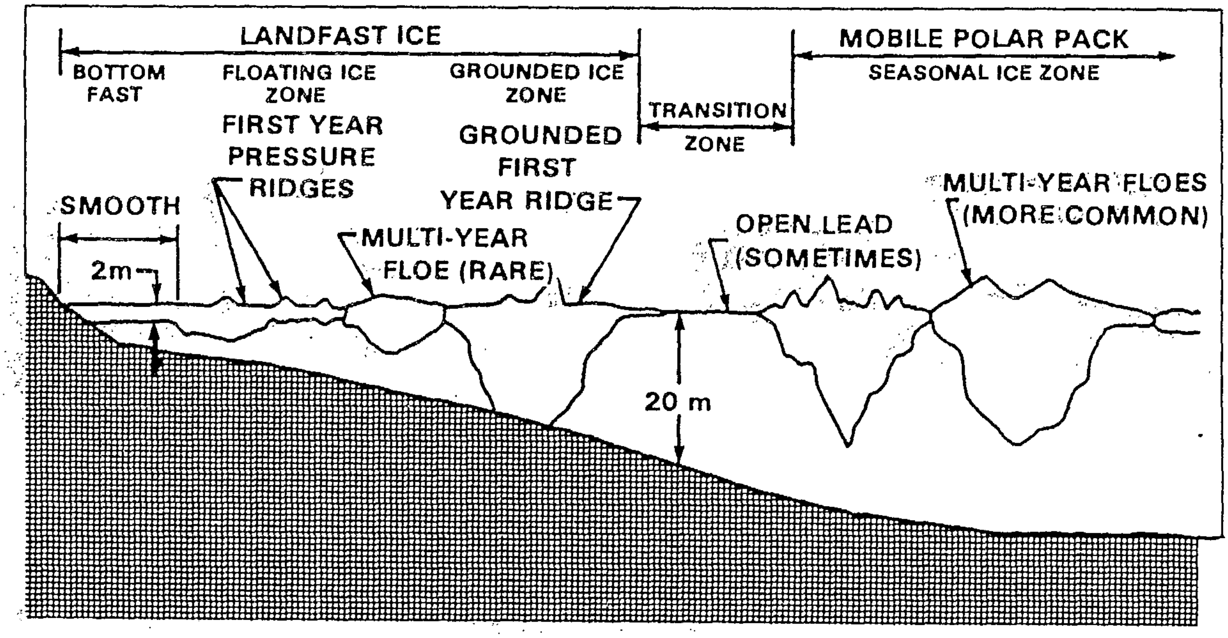
Map of Beaufort Sea Ice Zones



Source: Adapted from "The Northern Energy Research," Ottawa: Energy, Mines and Resources Canada, p.10.

Exhibit 7

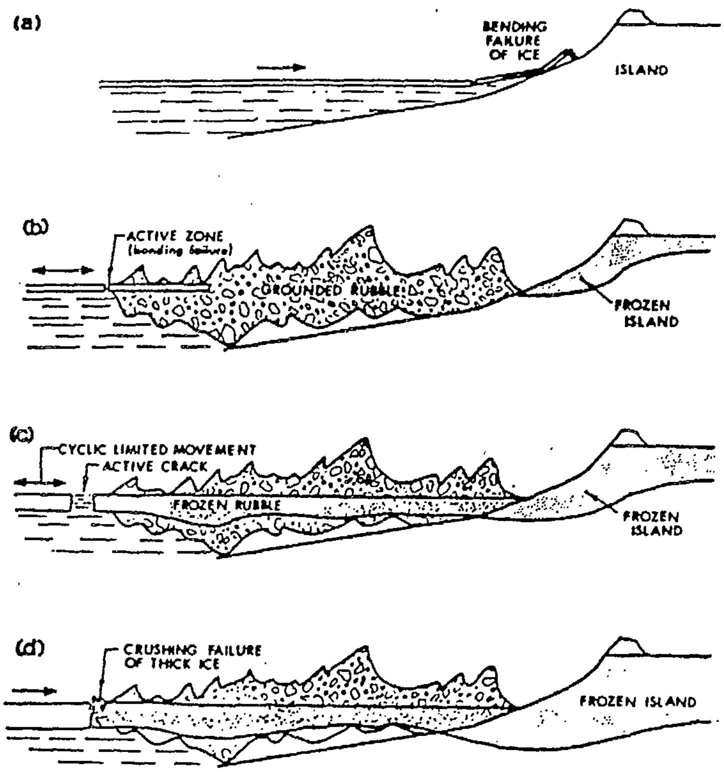
Corss-Section of Beaufort Sea Ice



Source: Company document

Exhibit 8

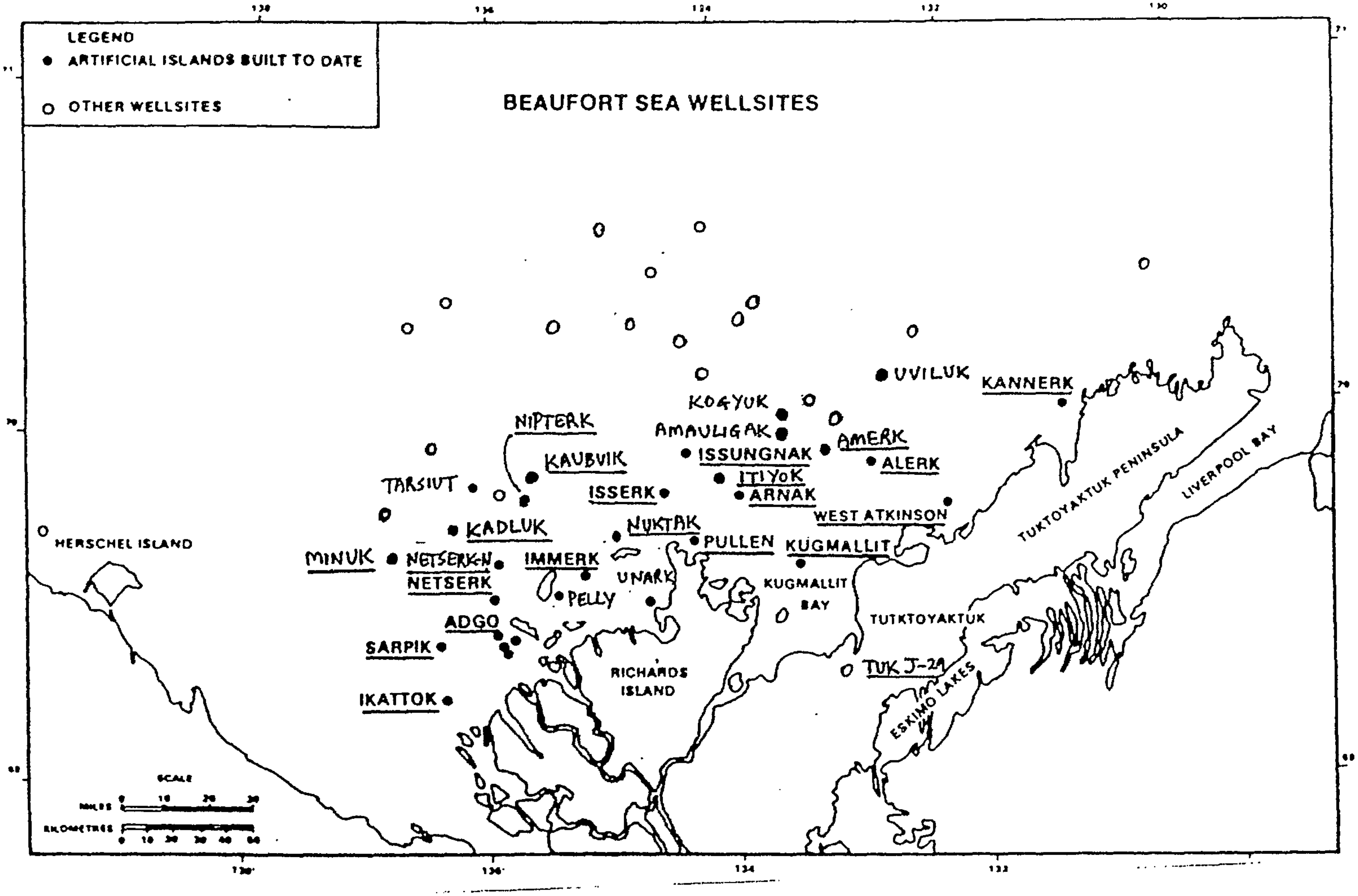
Formation of Ice Rubble Fields Around Islands



Source: Company document

Exhibit 9

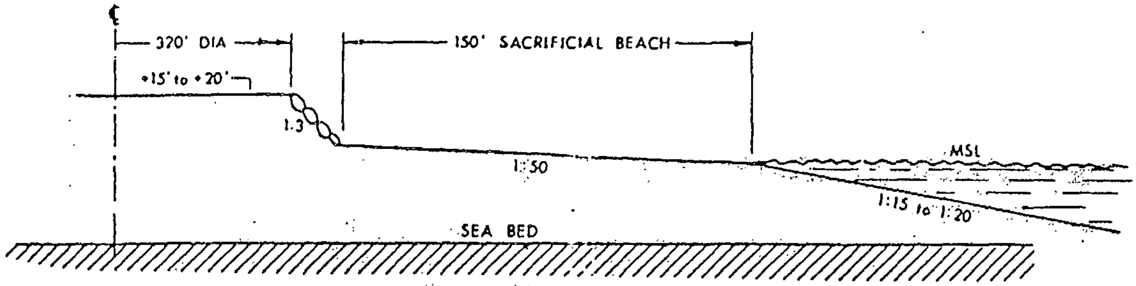
Map of Esso's Artificial Islands



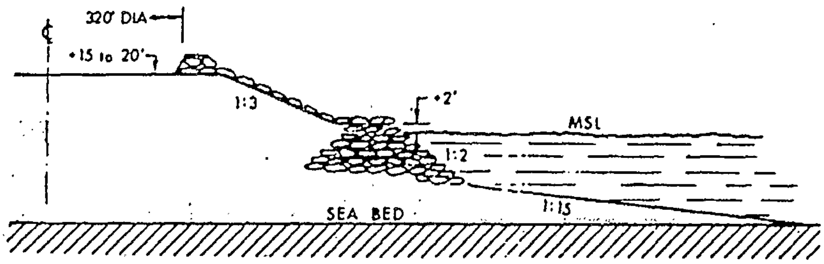
Note: *The names of Esso wellsites are underlined
Source: Company document.

Exhibit 10

The Sand-Bag Retained and Sacrificial Beach Islands



TYPICAL SACRIFICIAL BEACH ISLAND

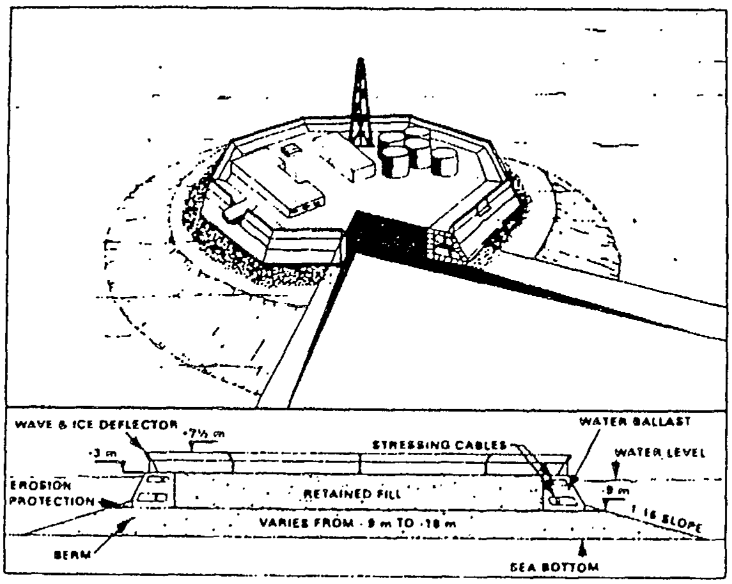


TYPICAL SAND-BAG RETAINED ISLAND

Source: Company document

Exhibit 11

The Caisson-Retained Island



Source: Company document