

TRANSFERS OF UNITED STATES AEROSPACE TECHNOLOGY TO JAPAN

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Economists have traditionally regarded the situs and dispersion of technology as exogenous factors, the concern primarily of historians.<sup>1</sup> Even though differential endowments of technology are of fundamental importance for the central body of economic theory and doctrine, there has been little attention to how these differences are established or modified. This situation is changing, however; many recent theoretical models and empirical studies incorporate the transfer or diffusion of technology,<sup>2</sup> but so far only a few case studies have explicitly treated the expected benefits that create a demand for someone else's technology, and the process and costs of meeting this demand.<sup>3</sup>

This paper is such a case study. It examines the circumstances that led to Japanese production of four U.S.-designed aircraft during the 1950's and 1960's,<sup>4</sup> the flows of requisite technology and other goods and services, and the costs of transferring the technology.<sup>5</sup> The history of this experience is instructive about the process and

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costs of one country's acquiring a sophisticated technical capability from another. Perhaps even more significant is a methodological implication to be derived from this study and others like it: that international flows of technology can be studied profitably by means of conventional market-force analysis. Such an approach can illuminate a number of the dark corners of economics and dispel some of the mystery concerning technology and economic change.

The aerospace industry is an exceptionally fertile source for the study of technology transfer.

There is an uncommon amount of public data on the industry, since international aerospace activities are usually under the cognizance of the governments concerned. Also, there have been numerous international manufacturing programs, involving a sizable total production, as can be seen from Table 1. From 1950 to 1967 more than ten thousand sophisticated aircraft, with a market value of over \$5 billion, were produced by firms under license from the original designers.

During this period, Japan was particularly active in acquiring aerospace technology, most of it from the United States. Their skill in doing so confirmed the reputation they have had for over a hundred years as skilled importers of technology; but economists have too often merely expressed their admiration for Japanese astuteness and left the matter there. Sociological and cultural factors are important, of course, but the relevant issue is how the Japanese actually formulate plans and proceed to acquire technology -- in short, what constitutes their skill. This paper addresses that issue.

Table 1

INTERNATIONAL PRODUCTION OF AIRCRAFT UNDER LICENSE, 1950-1967

(In \$ million)

Location of Licensors	Location of Licensee	Bombers	Fighters	Other Military	Heli-copters	Civilian Transports	Total
U.S.	Europe	--	(1,393) \$2,046	(100) \$3	(2,183) \$294	--	(3,676) \$2,343
U.S.	Other	--	(2,532) \$1,002	(568) \$241	(570) \$94	--	(3,670) \$1,337
Europe	U.S.	(403) \$484	--	--	--	(278) \$148	(681) \$632
Europe	Europe	--	(899) \$365	(669) \$109	--	--	(1,568) \$474
Europe	Other	(48) \$372	(669) \$109	--	(100) \$20	(44) \$66	(861) \$567
Total		(451) \$856	(5,493) \$3,522	(1,337) \$353	(2,853) \$408	(322) \$214	(10,456) \$5,353

SOURCE: R. E. Johnson and J. W. McKie, Competition in the Reprocurement Process, The RAND Corporation, RM-5657-PR, May 1968, p. 24. For data on the underlying programs, see Appendix C of the same study.

NOTE: Numbers of aircraft shown in parenthesis.

## II. SOME CONCEPTUAL CONSIDERATIONS<sup>6</sup>

We often speak of technology being transferred or knowledge migrating, but are seldom precise about the process involved.<sup>7</sup> Precision is important because technology is an abstraction and cannot move--- things and people are transferred, with attendant costs and benefits.

Technology can be transferred in two basic forms. One form embraces physical items such as drawings, tooling, machinery, process information, specifications, and patents. The other form is personal contact.<sup>8</sup> Put simply, knowledge is always embodied in something or somebody, the form being important for determining the transfer process and its costs. The process is simpler if knowledge is embodied in purely physical items. If it is embodied in people's expertise, a personnel transfer may be necessary -- often in the form of a "technical assistance" program. Within a single organization, the process may be more informal: people simply meet to talk or work together.

In any case, the ease and cost of transfer hinge on the industrial skill the recipient already possesses. A firm skilled in the manufacture of some general line of products -- voltage regulators, let us say -- will probably have little trouble in mastering the technology for a new regulator; in turn, the transferring firm will probably find it easy and inexpensive to impart the required information. The opposite will hold if the transfer entails a substantial advance in the technical level of the new producer. This fact has led us to distinguish among types of information that may be transferred. We refer to these as general, system-specific, and firm-specific technologies.<sup>9</sup>

General technology refers to information common to an industry, profession, or trade. At one extreme this category includes such basic skills as arithmetic, and at the other such specialized skills as blueprint reading, tool design, and computer programming. General knowledge, by definition, is possessed by all firms in an industry, and hence is the ticket of admission to the industry.

System-specific technology refers to the information possessed by firms or individuals within the group that differentiates each firm from its rivals, and gives a firm its competitive edge. Some of this specific information will have been acquired through engaging in certain tasks or projects. It comprises ingenious procedures connected with a particular system, solutions to unique problems or requirements, and experiences unlike those encountered with other systems. Information acquired by a firm in manufacturing an item, that is peculiar to that item, is defined as system-specific technology. Were any other firm to manufacture that item, it too would probably obtain the same technology.

Firm-specific knowledge differs from system-specific knowledge in that it cannot be attributed to any specific item the firm produces. Firm-specific knowledge results from the firm's over-all activities. Some organizations possess technical knowledge that goes beyond the general information possessed by the industry as a whole, nor would another firm manufacturing the same products necessarily acquire this same technology. For example, a firm may have special capabilities in thin-wall casting or metallurgical techniques not possessed by other firms, and not necessarily attributable to any specific item the firm has produced.

To illustrate the differences among the three types of technology, some of the information required for the manufacture of, say, the F-5 aircraft is common to all firms with an aircraft manufacturing capability; this we call general technology. The particular firm that manufactures the F-5 has acquired some specific information about this system not possessed by other firms; this is system-specific information. Certain other technology is possessed by this producer that other firms do not share, but which is not attributable to the F-5 (or other specific system); this is the producer's firm-specific knowledge.

The kind of information necessary for performing a certain task, and the form in which it is embodied, importantly influence the diffusion of technology and its costs. Diffusion and its costs in turn importantly influence vertical integration and the barriers to entry encountered by potential new suppliers.<sup>10</sup>

It is also important to consider the willingness of firms to make their technology available to others, and the difficulties and costs to a firm of obtaining access to required technology. A firm's willingness to diffuse technology depends on the form in which the knowledge is embodied and the extent to which well-functioning markets for technical information exist. Assume that a firm's specific technology is protected by property rights, e.g., by a patent, and that perfect markets exist both for property rights and for the products or services for which the technology is used. Then the firm should be indifferent to whether it sells the technology to other producers or uses it to produce goods and services. The value of the technology

to the possessor should be the same in both cases. If markets are lacking or highly imperfect at the product level, however, the firm may be forced to sell the property rights in order to realize a return from them. If markets for property rights are lacking or imperfect, it may pay the firm to use the technology within its own organization. If the technology is not invested with property rights, the firm cannot sell it and the best option is to try to keep the information secret and use it within the firm. In short, vertical integration depends importantly on the intellectual property system and the perfection of markets for both ideas and products.<sup>11</sup>

The ease with which a new firm can enter an industry depends on the considerations just discussed, as well as on the type of technology required to be an effective competitor. Established firms may be wholly unable to deter a new firm from obtaining the general technology it needs to enter an industry. If this information is publicly available, as in textbooks, other open literature, and skills of people in the general labor market, any new firm may be able to master the basic arts with minimum expense. Specific technology is a different matter; existing firms are likely to have some control over access, and may try to erect barriers to entry.

On the other hand, even if general technology is not openly available to a newcomer, existing firms may not strive to withhold it from a would-be new competitor. A well-established firm with many rivals may look with equanimity on having another competitor in the industry. It may be willing to render technical assistance at something like the direct costs involved in transferring the information.

A firm with few competitors, however, may look darkly on the arrival of another one on the scene, and be much less willing to provide technology.

These considerations go far to explain why international, inter-firm transfers of technology appear to be more common than intra-national, interfirm transfers. Market position, tariffs, transportation costs, and marketing costs are undoubtedly more significant internationally. Also, "political" considerations are often overriding in determining which firms will be allowed in a market. Consequently, the international market for technology is undoubtedly better developed than national markets. Internationally, firms often buy and sell technology in situations where domestically they would invest or do without rather than deal with a competitor.

Regardless of their attitude toward general technology, virtually all firms regard their specific technology as a valuable asset. Their attitude toward supplying information to other firms, however, may differ between firm-specific and system-specific technology. If a firm views its firm-specific technology as giving it a competitive edge over its rivals, the firm may be loath to divulge it. There is less concern over system-specific technology; in fact, there is a substantial trade (particularly international) in designs, process information, and the like. Two factors seem to be at work here. System-specific technology is more likely to be protected by patents or other property rights, or by generally accepted proprietary claims, so the original possessor has more protection in using the information and trade is easier. Probably more important, the firm

is likely to regard the technology as relevant only to one particular system. If another firm sets out to produce the system, it will re-discover the technology. That being so, the original producer is likely to regard transfer of the technology as merely saving the new producer time and expense, rather than revealing some secret that could have been maintained. Ordinarily, in short, system-specific knowledge is transferred more willingly than are other types of technology.

The important point is that one firm's willingness to transfer technology to another will partly depend on whether the technology is embodied in a form that can be sold, and upon the financial inducements. Willingness will also depend on whether the firm views the prospective recipient as a potential competitor. These factors in turn depend to a considerable degree upon the kind of knowledge required -- that is, on whether it is general, firm-specific, or system-specific.

The process of transfer and its costs also depend upon the nature of the technology to be transferred and the form of its embodiment. General technology will probably be more costly to transfer than will firm-specific knowledge, and firm-specific more costly than system-specific, because the latter is often embodied in patents, designs, drawings, tooling, and other physical forms. Even when system-specific information is embodied solely in personnel, the transfer is still less difficult than in other kinds of technology, since the task is merely one other way of teaching lessons learned.

Firm-specific technology may be embodied both in physical form and in "know-how" resulting from interpersonal working relationships

within an organization that are in some way difficult to separate from the firm as an entity. Firm-specific technology, therefore, can be costly to transfer.

The transfer of general technology may be the most difficult and costly of all, since it requires intensive yet broad education in practices and procedures peculiar to an industry. While these practices may be embodied in manuals and standard operating procedures, it may still necessitate costly experience to master them. Transfer of general technology blends into the process of general education for development.

All three types of technology were transferred in the co-production of aircraft by U.S. and Japanese companies. While the Japanese did not methodically use these categories in deciding what technology to acquire, the categorization may help us understand their decisions.

### III. EARLY CO-PRODUCTION PROGRAMS

#### THE REBIRTH OF JAPANESE AVIATION

Japan's impressive World War II aviation industry came to a halt in 1945. The Western Allies prohibited aircraft production and R&D activities until April 9, 1952. When the ban was lifted, the Japanese had virtually no aircraft capability. Wartime bombings, earthquakes, and other disasters had destroyed much of the plant and equipment, experienced personnel were retired or working in other fields, and postwar advances in aerospace technology left Japan's skills and equipment largely obsolete.

The rebirth of the industry can be roughly divided into three periods. The first period began with the lifting of the ban in 1952 and lasted until about 1954, when the F-86F and T-33A programs began. During this period, the industry concentrated on repair and overhaul work for the Japanese Air Self-Defense Force (JASDF) and the U.S. Air Force.<sup>12</sup> At the same time, R&D and prototype production took place for several trainers and liaison planes for the Japanese Defense Agency (JDA).

In the second period, from about 1954 to 1964, the industry added a substantial manufacturing effort to its overhaul and maintenance activities. Most of the planes produced were designed by U.S. firms, but Fuji Heavy Industries, Ltd., designed and produced two small jet trainers, and Ishikawajima-Harima Heavy Industries Co., Ltd. (IHI) developed and produced the J-3 jet engine. Several R&D programs were begun that appear to be coming to fruition in the third, or present period, which also includes the production of Japanese-designed commercial aircraft and the consideration of several new design efforts.

Japan's aircraft industry is small, having about 20,000 employees and above \$200 million in annual sales. Over 100 firms claim membership in the industry, but 5 firms account for most of the output. These firms, components of major zaibatsu, all have license agreements with U.S. aerospace firms, the ties being shown in Fig. 1. The middle column of Fig. 1 lists U.S. aircraft and engine systems manufactured in Japan from 1954 to 1966.

Between 1952 and 1964, the Japanese industry turned out 1422 planes with total sales prices amounting to \$781.7 (\$787.7 adjusted for price changes). Of this production, JDA took 1117, the U.S. Government 27, and domestic civilian customers 206, while 27 went for export and reparations. Manufacturing accounted for about three-fourths of the revenues earned, and repair and related activity for the rest.

Japanese aircraft manufacturing activity really began in earnest in 1957. Since that time the industry has turned out between 100 and 230 aircraft each year. Most have been produced under U.S. license, but in recent years the Japanese have been increasingly involved in design projects. A short-range Japanese turboprop airliner, the YS-11, is flying in several countries, including the United States. Plans are under discussion for production of a domestically developed interceptor and or a military transport.

The point is that in a very short period -- largely as a result of skillful importation of technology -- the Japanese acquired a small but capable and profitable aerospace industry. A key element in this accomplishment was the Japanese Government's sponsorship of military aircraft co-production programs. Co-production refers to interfirm transfers of

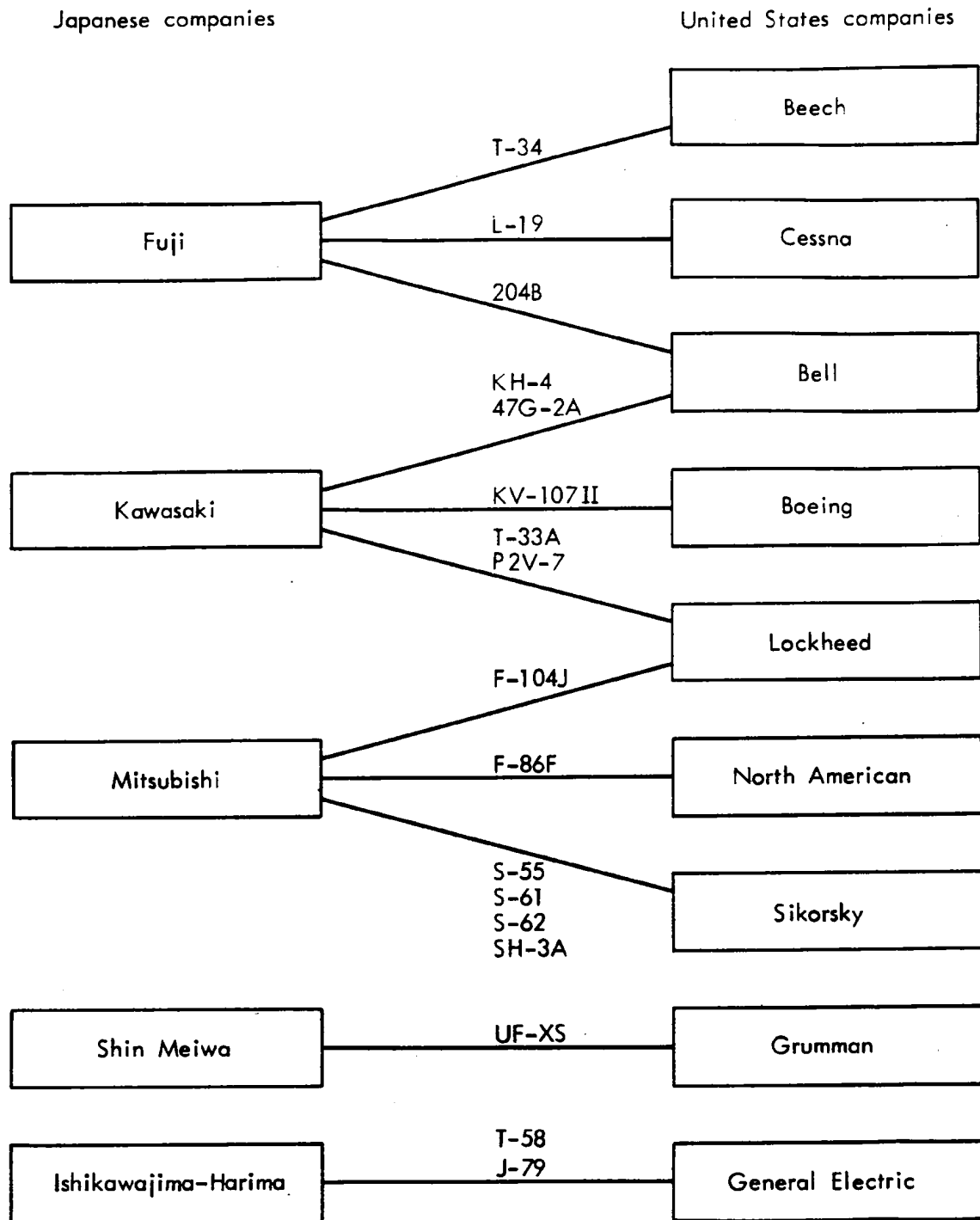


Fig. 1— U. S. planes, helicopters and engines manufactured in Japan

of manufacturing technology in which the developer of an item provides data, technology, and other assistance to enable another firm to manufacture the item. The first three programs were the manufacture by Mitsubishi Heavy Industries (MHI) of the North American Aviation F-86F fighter, and the Kawasaki Aircraft Company (KAC) manufacture of the Lockheed Aircraft Corporation's (LAC) T-33A trainer and P2V-7 antisubmarine aircraft. These programs established the industry and facilitated the later manufacture of the more sophisticated Lockheed F-104J interceptor.

Co-production programs illustrate the embodiment of technology and interfirm transfer processes. Further, since they permit us to examine the production of the same item in two or more countries, they provide a rich source of information about international cost relationships. This study focuses on the costs of transferring the F-104J technology from the United States to Japan, a program representative of many corporate transfers of technology between countries with developed industrial capabilities. To set the stage for this discussion, however, a brief summary of the technology Japan acquired under the early programs is in order.

#### General and Firm-Specific Technology

The transfer of general information about U.S. aerospace practices, firm-specific information about Lockheed and North American, and even some system-specific information about the T-33A and F-86F, had begun even before co-production was instituted. Japanese firms, including those later involved in the production progress, had contracts with the USAF for aircraft work; Mitsubishi, for example, had a contract for an

inspection-and-repair-as-necessary program for F-86 aircraft. This involved some importation of technology; for example, North American Aviation set up a small technical assistance program to support MHI. Mitsubishi officials state that both the direct experience with the F-86 system and the general familiarity it gained with NAA procedures and systems were helpful when the F-86F co-production program began.

Co-production increased the rate, amount, and kinds of technical information provided the Japanese by orders of magnitude. Both North American and Lockheed provided their co-production partners with extensive packages of data about corporate policies and practices, and there were many more contacts between American and Japanese personnel. For the F-86F program, for example, a group of MHI officials spent several months during 1956 at North American's facilities learning about NAA's operations. The data packages furnished contained detailed information about managerial, drafting, and other corporate procedures. Much of this information was embodied in manuals and statements of standard procedures.

It is easily seen that abundant general and firm-specific information was made available; it is much more difficult to determine how much the Japanese used and how valuable they found it. A number of stories about the early programs at both KAC and MHI, however, indicate the level of detail of the corporate information to which the Japanese had access and their interest in acquiring basic technology. For example, an NAA employee recalls that during the F-86 program Mitsubishi built a toolroom of beautifully grained Philippine mahogany. Instead of treating the wood in the traditional Japanese manner, it was painted dull green -- matching the color used in the Los Angeles NAA plant. The

resulting toolroom was indistinguishable from one of North American's.

This anecdote illustrates the close attention the Japanese firms paid to U.S. practices, but it does not mean they were slavish and unimaginative imitators. On the contrary, there were Japanese innovations and adaptations of techniques. During the F-86F program, for example, without assistance from the NAA technical assistance team, MHI developed a complex and ingenious new way to produce Monahan hinges, a portion of the airframe that had always posed difficult manufacturing problems for NAA.

The point of these stories is that the Japanese airframe manufacturers adopted a considerable body of U.S. general aerospace technology and Lockheed and North American firm-specific technology, but also innovated and adapted procedures.

On the vendor and subcontractor level, the transfer of general and firm-specific technology sometimes resembled that between prime contractors, and sometimes did not. The experience of some firms paralleled that of MHI and KAC. Others apparently possessed all the general and firm-specific information they were interested in, and consequently desired access only to system-specific technology. To illustrate, it appears that for generators and other electrical systems little technology except system-specific flowed to Japan. As an executive of one Japanese electrical firm said, "We had produced generators for fifty years. All we needed was the design."

#### System-Specific Technology

The transfer of system-specific information about the T-33A, F-86F, and P2V-7 is easier to analyze. In general, the Japanese received all

product designs and specifications and all process specifications. In particular, they had the benefit in every case either of the tooling or of the tool design information used by the developer in his production activities. They also received a great deal of planning paper. And since important data exist in the notes and black books of foremen and other production line personnel, these too were collected and made a part of the data package.

The blueprints, design drawings, and similar data transferred had to be adapted because of differences between manufacturing practices in the two countries. First, they had to be "upgraded," that is, made more detailed, because U.S. toolmakers and machinists are expected to surmise more than are their European and Japanese counterparts. Second, the data and drawings in the early programs had to be translated into Japanese and into the metric system. During the peak year (1956) of the F-86 program, for example, there was a design group at MHI of about 60 people. They devoted about 70 percent of their effort to converting drawings and specifications into the Japanese language and the metric system. From this experience MHI was subsequently able to use the Lockheed drawings for the F-104J program without translation.

Access to technical information was not a problem. When discussing data transfers, U.S. aerospace officials were emphatic in saying that their co-production partners could have access to any document. One U.S. executive flatly stated, "We were paid to put them in business, and we gave them everything we had." Nor does the story change when talking to Japanese executives. When asked if they would have liked fuller information from their U.S. co-production partners, the Japanese

invariably replied that they had no problem getting blueprints and other documents.

But what about the kind of information not found in documents? A considerable mystique is attributed to "know-how" in American industry. This know-how is assumed to be a part of the experience of men and organizations rather than written records. One relevant measure of its importance is the extent and function of technical assistance from the U.S. licensor. Each company provided advisors to its licensee as part of the program. It is instructive to note the size, composition, and function of these teams.

For the T-33A program, LAC sent 59 advisors to Japan. Because few of them stayed the full three years, the total number of man-years spent by LAC was considerably less than 177. The team included five administrators, one manager, one "leg man," one training specialist, one personnel man, eight to ten tooling specialists (who were in Japan for only one year), ten to fifteen manufacturing planners, two material procurement specialists, and production specialists or others with production experience. Lockheed hired some members of the group specifically for the program, but the tooling supervisor was a long-time LAC employee, and Lockheed considered it important to find tooling specialists familiar with Lockheed procedures.

The P2V-7 program also used a team of about 60 technical men. The contract called for 1462 man-months of overseas technical assistance; it also provided 775 man-months of technical assistance in the United States, and an allowance of up to 78 man-months for short-term and emergency specialists.<sup>8</sup> In both of LAC's programs, the full requirement

for technical assistance was supplied. The P2V-7 technical assistance program, therefore, was as large as the earlier T-33A program had been. LAC officials explain that the increased complexity of the P2V-7 system offset the savings gained from experience with the T-33A.

Compared with the LAC programs, the NAA technical assistance program was much smaller. No more than 29 employees were in Japan at a time. Fewer man-months of effort were expended on F-86F technical assistance; less than 400 man-months were expended on the entire program. Of the 32 people who worked on the F-86F, all had had similar responsibilities on other F-86 programs.

The technical assistance teams were coupled to the Japanese licensees in different ways by LAC and NAA. LAC used what it calls the "counterpart system." Each man who went to Japan was assigned a "counterpart" Kawasaki employee and an interpreter. This system meant that a group of three worked together, and each KAC employee was able to go up to the chain of command until he reached a supervisor with an American counterpart, from whom he was able to obtain assistance or advice. LAC argues that the best way to succeed in a co-production program is to participate directly in the problems of the partner. Indeed, LAC emphasizes that a large, integrated team is the key to co-production success.

NAA did not integrate its team with the MHI organization; instead the team made itself available for advice upon request, rather than being directly involved in MHI's activities. NAA believes that its system created less friction with MHI, a firm proud of its capabilities and achievements. The NAA system also required a smaller technical assistance team.

Both methods succeeded, but LAC believes that its procedures led to better airplanes and better success in meeting schedules. NAA and MHI both hold that schedules and quality were not serious problems for the F-86F program, and that some of the T-33A assistance provided by LAC was redundant. Although it would be foolhardy for any outside observer to attempt to assess the merits of these judgments, we can make some general observations about the size and kind of technical assistance given on these early co-production programs.

The NAA and LAC technical assistance efforts appear to have differed not only in size but also in the amount and kind of technology transferred. The NAA team was composed of NAA employees of long standing, most of whom had had extensive experience with manufacture of the F-86F. LAC, by contrast, hired some people with aerospace experience who had not necessarily worked for Lockheed or worked with the T-33 before they went to Japan. This evidence indicates that NAA viewed the technical assistance requirement as the transfer of the technology specific to the F-86F, while LAC was concerned with transfers of other types of technology as well, a fact which may explain the difference in the sizes of the teams. It may well be that most system-specific technology can be transferred in written form, and that the transfer of general and firm-specific technology requires a process of general education and occupational training with more personal interaction.

The relative importance attached to general and firm-specific technology as opposed to system-specific technology may partly be explained by differences between MHI and KAC. When co-production began in Japan, MHI was technically a more sophisticated firm than KAC. Thus the difference in the LAC and NAA team-sizes may also be partly explained by

the difference in the technological base of the two licenses: the larger the base, the less the general and firm-specific technology required. It is extremely difficult to analyze this hypothesis, however, because of personal considerations that confuse the data. KAC appears to have been more willing than MHI to enter into close working relationships with U.S. firms. The F-104J program, on which Lockheed worked with MHI, should provide some basis for comparison, since Lockheed is the only American company to have worked with both MHI and KAC. Unfortunately, that information is ambiguous. MHI felt that LAC preferred Kawasaki as the prime contractor. Suspicions and doubts between the two may have led to the more formal relationship for the F-104J program than had existed between LAC and KAC on the T-33A and P2V-7 program. The F-104J program, then, cannot readily be compared with these earlier co-production efforts.

While the amount of general and firm-specific technology transferred depends on the technology base of the licensee, it also depends on the sophistication of the system to be developed. Much of the technical assistance in the T-33A program was devoted to the transfer of general and firm-specific knowledge. The relatively large technical assistance effort required for the P2V-7, however, according to LAC sources, was due to KAC's need for the system-specific technology required for producing a more complex aircraft.

#### The Time Pattern of Transfer

All programs had the same general schedule. One or more planes of each model were manufactured and test-flown in the United States, then shipped to Japan. These were followed by other U.S.-manufactured aircraft

shipped in progressively less assembled form. These "knockdown" aircraft were reassembled by the licensee, who thereby gained experience in assembly operations. At some point in the program, when the licensee's own assembly tools were completely operable, knockdowns were replaced by shipments of component parts. As production tooling was completed, Japanese-manufactured parts entered assembly. Another major milestone was Japanese assumption of full manufacturing responsibility, with U.S. material support primarily limited to "hardcore" items. Although the U.S. licensor supplied some parts throughout the entire manufacturing stage, these decreased in number and importance as time went on.

The contribution of this phase-in procedure to the success of the co-production programs can hardly be overemphasized. It permitted the Japanese firm to meet relatively tight production schedules while learning from the licensor.

#### Tooling

The provision of tooling may be the most important part of the transfer process, insofar as the transfer of learning is concerned. It can be argued that a considerable degree of production efficiency is embodied in the design of the jigs and fixtures used by production personnel, because tooling design determines the basic physical relationships between men and machines. In all co-production programs, either tool design information or the actual tooling was transferred. While there is no way for us to judge the relative importance of these two transfers, provision of one or the other is the primary factor in the transfer of the developer's manufacturing experience to a new company.

There was considerable diversity among the programs. For the F-86F program NAA provided Mitsubishi with a complete set of tooling from their plant in Columbus, Ohio, which was being phased out of F-86 production. Most of the tooling was U.S. Government property, valued at about \$15 million. Some \$3 million worth belonged to NAA. The tooling was brought to Los Angeles, mastered<sup>13</sup> at NAA, and then shipped to Japan. MHI had to do some refurbishing of equipment, but in general there was far less toolmaking than starting from scratch would have required. It is impossible to quantify this statement, since MHI was building up its labor force and many people designated for production were assigned to tool building to keep them busy.

In contrast to the MHI F-86F program, KAC received only the mating tools required to control interchangeability for its T-33A production program. KAC received copies and plans necessary to reproduce all of the approximately 2000 tools required for the T-33A. To satisfy a USAF-JASDF requirement for interchangeability on four or five items, thirteen tools controlling the mating of those parts were produced in Burbank, California, from master tools there. This was the only tooling produced in the United States.

For the P2V-7 program, methods of both previous programs were used. KAC made some tools; it also bought 27 international master tooling gauges from IAC to control mating. KAC was also given two large shipments of production tooling owned by the U.S. Government and no longer needed by IAC. Naturally, this reduced KAC's toolmaking expense considerably.

The special tooling required for each program was extensive, involving thousands of items. Some items were manufactured in the United States,

but most were produced in Japan from designs, models, samples, and so forth, provided by the U.S. licensor.<sup>14</sup>

#### Parts and Manufacturing Support

The provision of parts and material support required two activities, interrelated and yet separate parts of the licensors' contractual obligations: (1) the provision of knockdown aircraft, component parts, hardcore parts, and raw materials from the United States, and (2) technical assistance in developing Japanese sources of supply.

The provision of knockdown assemblies and component parts has already been discussed as part of the interaction between phase-in and scheduling activities of production. Supply arrangements for items not produced by the U.S. co-production partner varied in each of the three programs. Lockheed dealt directly with its subcontractors for KAC. MHI procured items for the F-86F program directly from the NAA subcontractors. NAA also purchased a number of items for MHI that had been GFAE for the U.S. production of the F-86F. In all three programs, Government-furnished equipment was limited to engines, armament, and pyrotechnics, with minor exceptions.

Hardcore items were defined by the P2V-7 contract as those items to be furnished by the U.S. co-production partner that were "beyond the capability of the Japanese industry to produce or . . . economically unfeasible for production in Japan." Both U.S. and Japanese sources emphasize the effort made to minimize hardcore items. The Japanese Government was prepared to pay a premium to initiate domestic production. The U.S. firms assisted the implementation of this policy by accepting most of the items selected by the Japanese for the hardcore list. Many

items that were furnished as hardcore in the early programs were produced domestically in later ones, since each program increased the Japanese aircraft industry's capability.

The U.S. provision of tools, assemblies, parts, and materials served a number of ends. It assured international interchangeability of certain items. It decreased Japanese production costs by furnishing tooling the firms would otherwise have had to build, and by permitting importation of parts that would have been expensive to produce in Japan. As a result, Japan had to invest only a little less than \$17 million in facilities. U.S. supply also permitted tight delivery schedules for planes to JDA. Most important, manufacturing support permitted the transfer of technology at reasonable cost.<sup>15</sup>

#### Some General Observations

The three early programs, briefly summarized in Table 2, are interesting from many respects not least of which are the similarities and diversities among them.

The significance of the technology transfer goes beyond justifying the investment in facilities. There were some direct spillovers. For example, the landing gear on the Japanese YS-11 is an adaptation of that used on the P2V-7. Production of the F-104J was considerably easier because the Japanese firms had acquired substantial general and firm-specific technology through production of the T-33A, P2V-7, and F-86F. These programs also assisted Japan in the development and production of aircraft for both a domestic and a world market.

The results of these programs transcended the mere provision of 552 planes for the Japanese military forces. After all, planes could

Table 2

EARLY JAPANESE CO-PRODUCTION OF U.S. MILITARY AIRCRAFT

Program Feature	Type of Aircraft		
	T-33A	P2V-7	F-86F
Number of aircraft involved:			
Knockdowns from U.S.	20	6	10
Component parts from U.S.	10	7	60
Fabricated in Japan	<u>180</u>	<u>28</u>	<u>230</u>
Total	210	42	300
Items supplied from U.S.;			
Data <sup>a</sup>	limited rights and all data	limited rights and all data	limited rights and all data
Technical assistance	59 men	about 60 men	32 men
Tooling	13 key masters from U.S.; about 21,000 built in Japan from U.S. designs	27 key masters some production tools from U.S. rest built in Japan from U.S. designs	complete set from U.S.
Manufacturing support	selected parts, engines, armament	selected parts, engines, armament, some electronics	selected parts, engines, armament
Companies involved:			
U.S.	Lockheed	Lockheed	North American
Japanese	Kawasaki	Kawasaki	Mitsubishi
Period of Production	1955-59	1958-63	1955-61

been purchased from NAA and LAC assembly lines. The major achievement was Japan's acquisition of a modern aerospace manufacturing capability.

#### IV. THE F-104J PROGRAM

Mitsubishi's co-production of the Lockheed F-104J is particularly instructive on international transfers of technology. The program took place after MHI and the rest of the Japanese industry had had experience in manufacturing modern aircraft. The F-104 was relatively sophisticated, presenting some complex manufacturing tasks. Also, since the F-104J is a separate and distinct version of the basic F-104 interceptor, the transfer required some adaption of manufacturing technology. Finally, although a distinct model, the F-104J is sufficiently similar to F-104 models manufactured by Lockheed to permit some international cost comparisons. Specifically, the direct and indirect costs of transferring the F-104 manufacturing technology to Japan can be estimated. In addition, estimates can be made of the relative cost to the Japanese Government of producing the F-104J in Japan rather than buying aircraft off a United States production line.

#### DESCRIPTION OF THE PROGRAM

On November 7, 1959, Mitsubishi Heavy Industries was notified that it would be prime contractor for Japanese production of the Lockheed F-104 Starfighter, with Kawasaki Aircraft Company as a major airframe subcontractor.<sup>16</sup> In the intervening period between notification and contract effective date, a two-nation agreement was negotiated, the U.S. financial contribution was determined, a license was signed between MHI and Lockheed, and several purchase agreements and contracts were made between the companies concerned. The contract between Mitsubishi and the Japanese Defense Agency, signed March 31,

1961, initiated the C-1 program for the production of 180 F-104Js and 20 trainer planes, called the F-104DJ. This program ended March 1965; it was followed early in 1966 by the C-2 program, a contract for 30 additional aircraft.

The Japanese wanted a plane markedly different from the earlier F-104C plane produced by Lockheed. In particular they sought better electronics and a heavier airframe. Probably these major changes were influenced by the fact that a newer and more sophisticated version of the F-104, the F-104G, was being co-produced in Germany by a European consortium.<sup>17</sup> The Japanese were unhappy at the prospect of buying an F-104 that was not equal or superior to the German version in every way. The result was a significant design effort carried out both in the United States and Japan to modify the basic F-104 to obtain the F-104J version.

The license between Lockheed and Mitsubishi is valid for ten years. It provides for manufacturing rights, development activities, technical data, technical assistance, and all warranties. Only items designed by Lockheed are included in the license. LAC provides all data required for manufacture, including revisions during the license term. The assembly of the plane and all LAC-designed items are warranted, but not items of other firms' design. Mitsubishi has exclusive rights to sell the F-104J, but only to the Japanese Government. MHI agreed to pay LAC \$5.8 million to develop the J version of the airframe: a fixed fee of \$1.5 million for the manufacturing rights and data, plus a royalty on each plane made in Japan, this to be \$32,000 for the first plane, dropping to \$25,000 on the 201st plane. On spare parts

not purchased from LAC, MHI agreed to pay a 5-percent royalty.

The total C-1 program cost about \$269 million, of which the U.S. Government contributed \$75 million.<sup>18</sup> The C-1 program involved the Japanese manufacture of most of the airframe and J-79 engine components, plus assembly of some of the electronic items. Three F-104J planes were manufactured, assembled, and test-flown in the United States; 17 knockdowns and sets of component parts were manufactured in the United States and assembled in Japan; 160 F-104J planes were manufactured and assembled in Japan; and 20 F-104DJ planes were manufactured in the United States and reassembled in Japan. The C-2 program, the Japanese manufacture and assembly of 30 F-104J planes, increases in the proportion of engine components manufactured in Japan, and adds additional Japanese responsibilities for assembly and manufacture of electronics.

The LAC-MHI license agreement specified a technical assistance program of approximately 1400 man-months in Japan; the United States paid for this program. As a major subcontractor producing such items as the forward fuselage, the nose section, and the complete empennage, Kawasaki also received LAC technical assistance. The third technical assistance effort of any size was between General Electric Company and Ishikawajima-Harima Heavy Industries Company, Ltd. (IHI) for the production of the J-79 engine. General Electric provided 13 engineers, or about 131 man-months, at a total cost of \$285,000. Other licensors of parts and components also provided some technical assistance to licensees.<sup>19</sup>

Transfer of the extensive data and technical assistance furnished the Japanese co-producers was more complicated for the F-104J than for

earlier programs. For one thing, both configuration and design were more complex. The new configuration was defined by the basic F-104 design and a number of Engineering Change Proposals (ECPs). These ECPs resulted from Lockheed's experience with the F-104, and from the flight-test program for the new version. The Japanese, however, chose to assume configuration control quite early in the program -- following initial U.S. production -- with responsibility for acceptance or rejection of ECPs.

Lockheed retained responsibility for design control (which applies to the general characteristics of an aircraft rather than the specific configuration of the particular model) for a longer period than configuration control, but in time this responsibility also was transferred to the Japanese.

The problems associated with design and configuration control can be seen by reviewing the design activities of MHI and LAI. Lockheed provided six or seven men who worked with MHI's Engineering Department for about two years. From September 1960 through 1962, MHI had assigned 25 people to the F-104J program, of whom eight worked on electronics design. Relatively little translation of drawings and specifications into Japanese was required on this program; the group was occupied mostly in functional testing, solving engineering problems created by the new changes, and maintaining design and configuration control. The first two F-104J planes (numbered 3001 and 3002) were really modified F-104Gs. (These planes were characterized as similar to prototypes by one LAC executive.) The first true F-104J was the third plane, 3003. Since this plane was the product of an expedited

program, MHI had to do a great deal of work straightening out the design, correcting the parts lists, and so on. Lockheed's technical assistance program included a considerable amount of corrective and supplementary design work, mostly performed in Japan. At one point in the program, Lockheed proposed a program to insure international interchangeability of parts for the Japanese planes, but was unable to get it financed.

Unlike its experience with Kawasaki, which actively sought technical assistance, Lockheed found the Mitsubishi organization much more formal. Assistance was requested but there was not as close a relationship between the two firms as there had been between LAC and KAC. Indeed, Mitsubishi officials expressed skepticism about the need for such a large Lockheed technical assistance team. Since the technical assistance was paid out of the U.S. contribution, however, MHI was not inclined to protest the size of the effort.

The hardcore list for the F-104J reflects Japan's interest in increasing the capability of her aircraft industry. Subject to total budgetary restrictions, everything was built in Japan that could be. J. Horikoshi, an MHI official when the F-104J program was begun, lists the three objectives upon which selection of hardcore items was based: 1) to provide a domestic supply of items where a domestic source would assist operation and maintenance; 2) to use existing facilities, techniques, and licenses wherever economically feasible; and 3) to acquire facilities and processes that could also be useful in the later production of other aircraft and missiles.<sup>20</sup>

The license agreement called for LAC to provide MHI and its

subcontractors with master tools, gauges, fixtures, and other equipment not provided by either government. The Japanese imported the master tools from the United States in some cases; in others, they imported plaster copies from which they made their own master tools. They also purchased tooling for tricky designs or parts hard to produce from blueprints alone. LAC supplied 11 international masters, 23 plaster splashes of master mockups, 336 plaster splashes of other tools, 182 reproductions of master layouts, and 4843 Mylar reproductions of flat templates.<sup>21</sup>

Japanese imports would have been significantly different had Japan's total or monthly production been different. A hardcore list depends both upon the rate of production and the number of units produced, as can be illustrated in the European F-104 program. The consortium producing the F-104G, although they had a larger budget, bought fewer hardcore items and curtailed importation of many items from the United States earlier in their program than did the Japanese because the European program was larger than that in Japan.<sup>22</sup>

Japan already possessed most of the required technology and facilities. In Horikoshi's opinion the important technological capabilities acquired by the Japanese were limited to chemical milling techniques,<sup>23</sup> the spray-mat process to control icing,<sup>24</sup> and the improved capability to form and handle high-heat-treatment (4340) steel.<sup>25</sup>

The rapid development of Japanese capabilities for aircraft production is indicated by the decreasing number of items on the hardcore list. The initial hardcore list contained 226 items. By mid-1965 this number had fallen to 181. Further, 22 items originally procured

as finished parts were being shipped to Japan as rough castings and forgings at this time. LAC officials explain the classification of the 181 items on the final hardcore list on the basis of the three criteria that LAC and MHI used at their conferences (see Table 3):

- 1) Is the capital equipment expense too high to justify Japanese production?
- 2) Is the project tooling expense too high? or
- 3) Does Japan lack the necessary technical capabilities?

Table 3

HARDCORE ITEMS FOR F-104J PROGRAM  
CLASSIFIED BY PRICE AND REASON

Reason	No. of Line Items	Unit Price (\$)			
		0-100	101- 500	501- 1000	Over 1000
1) High capital equipment expense	25	19	3	2	1
2) High project tooling expense	70	42	20	7	1
3) Technical capability limitations	0	0	0	0	0
Combination of 1 and 2	76	27	47	2	0
Combination of 1 and 2	0	0	0	0	0
Combination of 2 and 3	3	0	0	3	0
Combination of 1, 2, and 3	7	0	2	4	1
Total	181	88	72	18	3

SOURCE: Lockheed Aircraft Corporation

As shown in Table 3, no item was classified hardcore solely from lack of technical capability; and in fact, for only 10 of the 181 items was this lack among the determining factors.

The price breakdown of Table 3, though crude, is revealing. The total cost of hardcore per aircraft was approximately \$38,000. The

items Lockheed supplied to Mitsubishi were primarily inexpensive; about half the total hardcore amount is accounted for by items costing from \$100 to \$500.

A hardcore list can be extensive for either of two mutually exclusive reasons: an item may be so sophisticated and complex that its manufacture would be difficult and expensive to transfer to another firm; or an item may be so simple and widespread in application as to be uneconomical to produce except in large quantities. In the first case, the high costs of transfer could place the item on the hardcore list. In the second case transfer, although probably inexpensive, might be unattractive because of the economies of scale. The F-104J hardcore list reflects economies of scale more than high costs of transfer. The relatively few expensive items on the F-104J hardcore list include the air intake duct inner skins, radomes, wing skins, fuselage main frames, fuselage keelsons, empennage beams, and fuselage longerons. Inexpensive items included because of the economies of scale were mostly small pieces of hardware such as blind rivets and hi-lock bolts.

In addition to the hardcore items, electronics components such as the NASARR fire control system and the optical sight system were purchased from the United States. These purchases accounted for a much higher proportion of the total system cost than did the hardcore items.

Government-furnished aerospace equipment for the program consisted of the engines, some purchased from General Electric, some from Japan's jet engine producer, IHI; the ARC 552 UHF radio; the ARN 52 TACAN

(Tactical Airborne Navigation Equipment); the APX 35 IFF (Identification, Friend or Foe); the KB-3A gun camera; the tires, pyrotechnics, and guns.

This general description of the F-104J program affirms the significant technical achievement of Japanese co-production, but two questions remain unanswered: First, how much of the F-104J was really Japanese-produced (or how much was merely Japanese assembly of U.S.-manufactured items)? And second, what was the cost of transferring the necessary technology? This latter question will be examined in the next section. Here we address the first question.

To determine the extent of the F-104J technology transfer, we need to determine the purchases made by Government contractors from vendors and subcontractors, plus the value-added of the firms. Aided by MHI and LAI officials, we visited and obtained data from leading suppliers of F-104J parts and components. The sample included five suppliers of airframe items, the engine manufacturer, and three electronics companies. We soon found that the airframe, engine, and electronics firms differed widely in their degree of involvement.

To understand the contribution of these three groups, and to provide a comparison for the cost figures to be presented, Table 4 shows the average costs for 60 F-104Gs purchased in the United States in 1964. The G version being similar to the J version, it provides a good basis for cost comparisons. Note that the airframe accounts for approximately two-thirds of the cost of the system, and the engine and electronics for about one-sixth each.

Table 5 presents more basic data on sources of supply. As this

Table 4

FLYAWAY COST OF F-104G MAP AIRCRAFT,  
FISCAL YEAR 1964<sup>a</sup>  
(In \$ thousand)

Item	\$	%
Airframe	789	65.8
Engine	184	15.3
Electronics <sup>b</sup>	227	18.9
Total	1200	100.0

<sup>a</sup>Based on information provided by the F-104 SPO on a FY 1964 MAP procurement of approximately 60 aircraft.

<sup>b</sup>Includes estimated prices of miscellaneous items of GFAC.

table shows, MHI, the prime contractor, produced about 80 percent of the total value of the airframe. As the major subcontractor, KAC was responsible for the complete empennage, the forward and aft fuselage sections, and some other items. Table 5 shows the MHI and KAC parts of the C-1 program divided among outside domestic purchases, imports, and the value-added by the firm. The 20 trainers and 20 knockdowns, in which MHI and KAC were only middlemen for LAC, are not shown. The discussion is limited to the 160-aircraft portion of the program and its related spare parts production. In addition to the total airframe imports of MHI and KAC, paid for by JDA, the MHI imports include the hardcore items that were purchased from LAC with the U.S. dollar contribution.<sup>26</sup>

About 31 percent of MHI's purchases and about 33 percent of KAC's were imported. Compared with the total cost of manufacture, imports

Table 5

PRODUCTION EXPERIENCE OF MHI AND KAC IN  
160-AIRCRAFT PORTION OF C-1 PROGRAM

(In \$ million)

Item	MHI		KAC <sup>a</sup>	
	\$	%	\$	%
Imports <sup>b</sup>				
Raw material	1.89		0.71	
Parts	12.00		2.81	
Hardcore <sup>c</sup>	6.06			
Total imports	19.95	17.1	3.52	18.0
Domestic purchases				
Raw material	1.32		1.06	
Parts	20.48		6.09	
KAC subcontract	22.84			
Total domestic purchases	44.64	38.3	7.15	36.4
Value-added by firm	51.94	44.6	8.95	45.6
Total	116.53	100.0	19.62	100.0

<sup>a</sup> Excludes spare parts and the assembly work on the first 20 F-104J aircraft.

<sup>b</sup> Airframe experience only (excludes MHI import of \$23.45 million of electronics).

<sup>c</sup> Purchased separately from LAC out of U.S. dollar contribution.

were about 17 percent for MHI and about 18 percent for KAC. Hardcore items accounted for about 30 percent of MHI's imports. Raw material imports were relatively insignificant. Most of the items purchased by the Japanese prime contractor and the major subcontractor came from Japanese firms.

We see from Table 5 that the percentage of value added by MHI is 44.6 and KAC is 45.6. These numbers provide a check on our conclusions about the transfer of technology. Had the value-added percentages

for the Japanese firms been markedly lower than in the United States, we would have suspected that the Japanese firms were merely shipping U.S.-produced items and that no significant transfer of technology had occurred; but the MHI and KAC value-added figures are about the same as average value-added figures for U.S. aerospace industries. Separate data are not available for the F-104 program, but, as can be seen from Table 6, figures of around 44 or 45 percent are common on a company-wide basis.

Table 6

PERCENTAGE VALUE-ADDED FOR SELECTED U.S. AEROSPACE FIRMS<sup>a</sup>

Boeing Company .....	45.5
Douglas Aircraft Company, Inc. ....	47.9
General Dynamics Corporation .....	45.8
Lockheed Aircraft Corporation .....	44.2
McDonnell Aircraft Corporation .....	44.0

<sup>a</sup>Average annual value for the years 1961-1964. Compiled from corporate financial statements by dividing total sales into the total amount shown for wages, profits, interest, depreciation, and taxes.

Mitsubishi purchased about \$22 million worth of items from Japanese firms other than KAC, as shown in Table 5. To obtain a picture of the relative Japanese and U.S. contributions to the F-104J, therefore, it is necessary to go below the prime contractor level and examine the source of inputs for the Japanese vendors. Table 7 lists the major airframe vendors, the products they supplied, and the relevant U.S. licensors. We need the same breakdown of the contributions of these firms that was presented for MHI and KAC in Table 5.

Table 7

AIRFRAME VENDORS IN THE F-104J PROGRAM<sup>a</sup>

Company	Products Supplied	Licensor <sup>b</sup>
Bridgestone Tire Company, Ltd. Chuo Spring Company, Ltd. Daikin Kogyo Company, Ltd. Dainichi-Nippon Cables, Ltd. Fujiwara Industry Company, Ltd. Furukawa Aluminum Company, Ltd. Hitachi Wire and Cable, Ltd. Japan Aircraft Manufacturing Company, Ltd. Japan Aviation Electronics Industry, Ltd. Kayaba Industry Company, Ltd. Kobe Steel Works, Ltd. Koito Manufacturing Company, Ltd. Koyo Seiko Company, Ltd. Mitsubishi Electric Corporation Mitsubishi Rayon Company, Ltd. Shimadzu Seisakusho, Ltd. Shinko Electric Company, Ltd. Shin Meiwa Industry Company, Ltd. Sumitomo Electric Industries, Ltd. Sumitomo Precision Products Company, Ltd. Tateisi Electronics Company, Ltd. Teijin Seiki Company, Ltd.	Tires Springs, control wires Landing gear & hydraulic parts Rubber products Canopies, windows Aluminum products & forgings Electric wires Airframe parts Gyroscopes, gauges Brakes, valves Castings and forgings Aircraft lights Bearings Fuel pumps, electrical products Airplane glass Air conditioning systems, valves Generators, voltage regulators Tip tanks Fuel tanks Landing gear components Microswitches Hydraulic parts	Swedlow, Inc. <sup>c</sup>  Minneapolis-Honeywell Bendix Corporation  Bendix Corporation  Thompson Ramo Wooldridge Swedlow, Inc. Garrett Corporation Bendix Corporation  Cleveland Pneumatic  Haskell Engineering

<sup>a</sup> The companies listed supplied products to either MHI or KAC, or both, during the C-1 Program. Only major suppliers are included, as identified from material contained in The Aircraft Industry Yearbook, Japan Aircraft Industry Society, Tokyo, 1965, pp. 189-298.

<sup>b</sup> Includes only licensors of specific products designed for the F-104J.

<sup>c</sup> Under a license arrangement with Mitsubishi Rayon Company.

MHI officials provided a list of that company's leading vendors and the amounts paid to each, showing that two-thirds of all domestic purchases were made from nine leading suppliers. Three suppliers accounted for over one-third of the total purchases.

Information gained from these three suppliers about their production experience is given in Table 8. The three firms illustrate three different situations with respect to domestic supply.

Table 8

PRODUCTION EXPERIENCE OF THE THREE LARGEST MHI VENDORS,  
160-AIRCRAFT PORTION OF THE C-1 PROGRAM  
(Percent)

Item	Shinko Electric Co., Ltd.	Shimadzu Seisakusho Ltd.	Sumitomo Precision Products Co., Ltd.
Imports	9.5	61.3	32.3
Raw materials			11.8
Parts	9.5	61.3	20.5
Domestic purchases	14.4	11.9	46.3
Raw materials	5.3	3.4	4.1
Parts	9.1	8.5	42.2
Value-added by firm	<u>76.1</u>	<u>26.8</u>	<u>21.4</u>
Total	100.0	100.0	100.0
Products	generators volt. reg.	air cond. starters	landing gear
% MHI purchases	9.3	14.7	13.1
U.S. licensor	Bendix Corp.	Garrett Corp.	Cleveland Pneumatic

Shimadzu's experience has special interest. Over 80 percent of its sales to MHI were accounted for by one product -- the air conditioning system. Because this highly compact and very sophisticated system was unlike anything the firm had previously manufactured, most

of the parts were imported from the U.S. licensor, the Garrett Corporation. Because of this one product, approximately 61 percent of Shimadzu sales to MHI were foreign product imports. There appears to have been a severe barrier to the transfer of technology, perhaps resulting from the extreme difference in the technological base of the licensor and licensee. This heavy reliance on imports is not a general characteristic of the Shimadzu firm. Under another Garrett license, Shimadzu manufactured an electric actuator. Imports for this simpler item, of which Shimadzu was an experienced manufacturer, accounted for only 17 percent of total sales.

Sumitomo Precision represents an intermediate case, making extensive use of domestic and foreign inputs. It manufactures landing gear components under a license with Cleveland Pneumatic, as shown in Table 8, with imports accounting for about one-third of the total sales of MHI. At the time of the C-1 program, the Japanese industry lacked a capability for forging hard steel (especially forgings that require large-capacity double-action presses).<sup>27</sup> Many of the imported items required hard-steel forgings with only modest amounts of machining. The relatively heavy reliance on domestic purchases reflects primarily the involvement of Daikin Kogyo Company, Ltd., one other firm producing landing gear components.

The experience of Shinko Electric shows the third position on imports. Note the very low reliance on imports, even though the products are somewhat complex (voltage regulators, generators, etc), manufactured to Bendix Corporation designs. Officials of Shinko state they had almost no difficulty in manufacturing the items they supplied.

The reason for importing parts from the United States was primarily comparative manufacturing costs; the imports were not necessarily the most sophisticated parts, and there had been practically no technical interaction between licensor and licensee.

To summarize, it appears that most of the airframe technology was transferred from the United States to Japan. Much of the F-104J airframe was manufactured in Japan, and U.S. imports of finished items accounted for a relatively small part of the airframe value. There was a very gradual and, on the whole, modest decline in the reliance on imports during the C-1 program. And according to C-2 program estimates provided by the firms involved, reliance on imports and outside domestic purchases (for 30 follow-on craft) is expected to remain virtually unchanged for MHI, KAC, and the three leading MHI vendors.

Differences among the MHI vendors in their reliance upon imports reflect the differences in the process of transferring a particular type of technology. When only system-specific information is required, transfer is easy and inexpensive even if the item is complex and the technology sophisticated. Transfer appears more difficult for items substantially different from a firm's current product. In this case, licensees are likely to rely much more heavily on imports of finished items from their licensors.

In sharp contrast to the modest decline in imports for the airframe portion of the F-104J, the role of imports in engine co-production changed dramatically. The first 29 "Japanese" engines (procured by the Japan Defense Agency from the prime contractor) were actually

supplied from the United States as partly assembled knockdowns. By the end of the C-1 program, imports accounted for less than one-third of the total invoice price. IHI is the prime contractor for the J-79/GE-11A engine. Table 9 lists the major suppliers for manufacture of the J-79 engines, with an indication of the types of components each firm produces. Both KAC and MHI are subcontractors on the engine portion of the program. Table 10 indicates the average cost experience for the C-1 program, and the IHI estimates for the follow-on C-2 program. Most impressive in the data in Table 10 is the difference between the C-1 and the C-2 programs in the reliance on imports. Over

Table 9

ENGINE VENDORS IN THE F-104J PROGRAM

Company	Product Supplied	Licensors <sup>a</sup>
Kawasaki Aircraft Company, Ltd. <sup>b</sup>	Engine parts	
Mitsubishi Heavy Industries, Ltd. <sup>b</sup>	Starters	Preumo Dynamics Corp.
Nippon Seiko Company, Ltd.	Bearings	
Nittoku Metal Industry Company, Ltd.	Turbine and compressor blades	Kelsey Hayes Company
New Tachikawa Aircraft Company, Ltd.	Engine parts	
Teijin Seiki Company, Ltd.	Fuel pumps, nozzles	Bendix Corporation
Toyo Bearing Manufacturing Co., Ltd.	Bearings	
Yokogawa Aviation Company, Ltd.	Ignition system parts	Bendix Corporation

NOTE: The companies listed supplied products to IHI during the C-1 program. Only major suppliers are included, as identified from material contained in Japan Aircraft Industry Society, Aircraft Industry Handbook, Tokyo, 1965, pp. 189-298.

<sup>a</sup> Includes only licensors of specific products designed for the J-79 engine.

<sup>b</sup> KAC and MHI were IHI subcontractors (rather than vendors) in the C-1 engine program.

Table 10

IHI PRODUCTION EXPERIENCE OF J-79 ENGINES: 160-AIRCRAFT PORTION  
OF THE C-1 PROGRAM AND C-2 PROGRAM ESTIMATES  
(Percent)

Item	Program	
	C-1	C-2
Imports	51.3	24.5
Domestic purchases		
MHI subcontract	6.1	9.4
KAC subcontract	1.7	2.5
Other	5.4	19.4
Total domestic purchases	13.2	31.3
Value added by IHI	35.5	44.2
Total	100.0	100.0
Program size (\$ million) <sup>a</sup>	44.39	7.14

SOURCE: Percentages of total IHI receipts are taken from data supplied by IHI, shown in full in Appendix D, Table 42.

<sup>a</sup>Contract information supplied by JDA.

half the price of an engine can be attributed to U.S. imports in the C-1 program, while in the C-2 program imports are expected to be less than one-quarter of the price.

When we examined the list of C-2 program imports from General Electric Co. with officials from IHI, we noted only a handful of components having unit costs of \$500 or more -- a small fraction of the number of such components imported for the C-1 program. A few major components supplied by U.S. vendors will still be imported, including scavenge pumps from Lear-Siegler, flow dividers from Parker-Hanisfinger, and oil pumps from United Aircraft; a few expensive

components such as anti-icing valves, main oil cooler valves, afterburner oil coolers, control assemblies, and emergency pumps will continue to be purchased from GE, but the bulk of the imports will be small items -- "nuts and bolts," in the words of one IHI official.

Let us compare the IHI figures with those in Table 5 for MHI and KAC. IHI expects a value-added of about 44.2 percent for the C-2 program, or about the same as that of MHI and KAC for the C-1 program. But note that, in the C-1 program, IHI "in-house" work accounted for only about 35.5 percent of the total engine price. Domestic purchases differ even more. For the C-1 program only 13.2 percent of the engine price was spent on IHI purchases from Japanese firms; comparable figures for MHI and KAC were 38.3 and 36.4 percent. IHI's percentage of domestic purchases will be about 31.3 for the C-2 program. IHI's sources of supply for the C-2 program are about the same as MHI's and KAC's were for the C-1 program. This means that Japan's engine self-sufficiency has just now reached the stage its airframe self-sufficiency arrived at five years earlier.

Most F-104J electronics were not co-produced in the same sense that the airframe and engine were co-produced. The 20 F-104DJ aircraft and the first 20 F-104J aircraft were completely equipped with electronics from U.S. suppliers. For the remaining 160 F-104J aircraft in the C-1 program, 160 sets of major items of electronics were imported already assembled. Of these, 110 were financed by the Japanese contribution to the program (through MHI), and 50 were supplied out of the U.S. financial contribution (through LAI). The other electronics for the C-1 program were treated as GFAE by JDA. The JDA purchased

160 sets of miscellaneous items from Japanese firms, including the radio, TACAN, IFF, and the gun camera. They also purchased spare units of the principal electronics items from Japanese firms. Japanese firms performed electronics manufacture only for spare parts and some miscellaneous components.

To learn about the Japanese role in providing spare electronics units, we assembled data on the NASARR Fire Control System (procured from Mitsubishi Electric), the stable platform (procured from Mitsubishi Precision), and the air data computer (procured from Shimadzu). Table 11 lists average unit cost of each major item of electronics imported. These three items accounted for approximately three-fourths of the total cost. The results of the investigation are shown in Table 12. Imports accounted for over 75 percent of the total sales price. It became apparent from discussions that the Japanese had only assembled and tested imported parts.<sup>28</sup>

The relative costs of imports and domestically assembled components for the electronics part of the F-104J program are high. The average unit cost of the completed items imported is about 20 percent lower than the cost of the parts for the components assembled in Japan. Table 13 compares the average prices paid by the Japanese Government for the components assembled in Japan with the unit costs of complete components imported from the United States (also shown in Table 11). Subtracting the value-added in Japan from the unit cost gives figures for the cost of the imported parts used in assembly. The costs of these parts are uniformly higher than the costs of the complete components imported.

Table 11

UNIT PRICES OF ELECTRONICS SUPPLIED BY  
U.S. FIRMS FOR THE F-104J PROGRAM<sup>a</sup>

(In \$ thousand)

NASARR fire control system ...95.5  
Autopilot .....40.7  
Stable platform .....31.5  
Air data computer .....23.2  
Director gunsight .....11.5  
In-range computer ..... 4.8  
Total .....207.2

SOURCE: Military Air Assistance  
Group, Japan.

<sup>a</sup>In 1960 prices for 160 ship sets.

Table 12

SELECTED JDA EXPENDITURES ON ELECTRONICS: C-1 PROGRAM<sup>a</sup>

(In \$ million)

Item	Qty	Supplier	Imports	Value Added in Japan	Total
NASARR	27	Mitsubishi Electric	3.2	0.9	4.1
Stable platform	24	Mitsubishi Precision	0.9	0.4	1.3
Air data computer	24	Shimadzu Seisakusho	0.6	0.2	0.8
Subtotal			4.7	1.5	6.2
Percentage			75.8%	24.2%	100.0%
All other purchases by JDA					7.7
Total					13.9

<sup>a</sup>Expenditures itemized by firm cover only the assembly of spare units in Japan when all parts are imported. The portion not itemized by firm is for the purchase of 160 sets of miscellaneous items, including radios, TACAN, IFF, and gun cameras. Table 41, Appendix D, gives details for the more important purchases.

Table 13

AVERAGE UNIT COSTS OF SELECTED ITEMS OF ELECTRONICS  
(In \$ thousand)

Item	U.S. Unit Cost	Qty	U.S.-Supplied Imported Parts Used in Assembly	Spare Units Assembled in Japan		
				Value- Added in Japan	Total Unit Cost, Japan	Qty
NASARR	95.5	160	119.4	33.1	152.5	27
Stable platform	31.5	160	36.8	16.5	53.3	24
Air data computer	23.2	160	26.5	8.1	34.6	24

The implication of these data is that the Japanese electronics assembly part of the program is being subsidized by the Japanese Government to enable Japanese manufacturers to gain familiarity with the more sophisticated electronic products.<sup>29</sup> One possible explanation is that there are important barriers to the transfer of technology associated with the manufacture of the major items of military electronics.

SUMMARY

Some key features of the F-104J program are shown in Table 14. A major share of the fabrication of the F-104J took place in Japan, but the extent to which U.S. technology was transferred varied considerably among different parts of the program. Most of the airframe was produced in Japan after the first 20 aircraft were assembled. By 1966 most of the engine was produced in Japan, but it took the entire C-1 program for the necessary technology to be transferred completely. Very little of the technology for the electronics can be said to have

Table 14

JAPANESE CO-PRODUCTION OF THE F-104J

Number of aircraft involved:

Knockdowns from U.S. ....	7
Component parts from U.S. ....	10
Fabricated in Japan ....	190
Total .....	207

Items supplied from U.S.:

Data .....	limited rights and all data
Technical assistance .....	about 60 men
Tooling .....	11 key masters and over 5000 plaster splashes and Mylar reproductions. Tooling built in Japan from U.S. designs.
Manufacturing support .....	selected parts, some engines, arma- ment, most electronics.

Companies involved:

U.S. ....	Lockheed
Japanese .....	Mitsubishi

Period of production ..... 1961-67

been transferred. In dollar terms, the airframe accounts for about 60 percent of the cost of the aircraft and the other two categories for about 20 percent each.

Through previous IRAN and airframe co-production programs, Japanese airframe manufacturers had acquired substantial command over most of the general airframe manufacturing technology. Since very little general technology was required, the transfer was rapidly accomplished. The airframe situation also appears characteristic of various component suppliers such as Shinko Electric, the generator producer.

The electronics situation contrasts sharply with the airframe experience. Japan's reputation in the field of commercial electronics might lead one to expect that the F-104J electronics gear would be

manufactured in Japan without difficulty. In fact, however, little electronics manufacture took place on the C-1 program. Most major electronics items, such as the NASARR Fire Control System, were simply imported from the United States.

The explanation given by Japanese executives is that there are substantial differences between sophisticated military electronics and the commercial field in which Japanese firms are experienced -- both in physical characteristics and in specifications. This indicates that production of items such as the NASARR or the stable platform would have required the transfer of general technology associated with the military electronics field rather than merely the specific technology associated with the particular systems.

Through assembly and spare parts manufacturing, the Japanese are generally acquiring the general technology of military electronics. Perhaps future co-production programs will show a pattern in electronics more like that in the airframe portion of the F-104J program.

The J-79 engine experience tends to support this prediction. Unlike electronics, the Japanese had some experience in jet engine production at the outset of the C-1 program; by the end of the C-1 program the engine was produced almost entirely in Japan. The transfer process for engine technology took much longer than did the airframe, probably because the Japanese had had extensive prior experience in airframe production, which gave them a relatively large stock of general manufacturing technology.

The F-104J experience illustrates that the transfer of technology need not be an all-or-nothing matter. The ability to import parts,

supplies, materials, and technical assistance permits a gradual and partial transfer of the technology required for an item. This process is well exemplified by the engine and electronics portions of the program.

The F-104J experience suggests that the ease of transferring manufacturing technology for an aircraft importantly depends upon the amount of general knowledge that must be included in the transfer. If the backgrounds of the firms are so different that the transfer of general technology is necessary, a firm is likely to limit its initial activities to assembly and repair -- activities that appear to facilitate the gradual transfer of general technology.

## V. THE ECONOMICS OF TRANSFER

Two classes of costs associated with the transfer of production from one firm to another will be considered in this section. First, direct costs represent the financial outlays required to move the necessary technology. Second, indirect costs take the form of increased production costs incurred because manufacturing responsibility is divided rather than concentrated within a single firm. After consideration of the direct and indirect costs of transfer, the total cost of producing the F-104J will be compared with that of another F-104 model produced in the United States. Because they showed generally similar trends in production costs, only occasional reference will be made to the co-production programs that antedated the F-104J.

### Direct Costs

The main direct costs incurred in transferring technology for U.S. aerospace systems to Japan were license fees, royalties, and technical assistance payments.<sup>30</sup>

Considering royalties and license fees first, each Japanese producer of a U.S. proprietary item had to make some financial arrangement for manufacturing and data rights. MHI agreed to pay LAI \$1.5 million plus a royalty on each aircraft. This royalty averaged about \$31,500 for each of the 160 F-104Js manufactured in Japan during the C-1 program. As a percentage of the total price of airframes produced in Japan, the payments for rights generally followed the pattern set in the earlier programs.<sup>31</sup>

There were many additional license agreements at the vendor level;

the most important of these were listed in previous tables. Royalties usually amounted to about five percent of the invoice price of the licensee's product, with a modest initial payment or none at all. That portion of the invoice price represented by parts and materials purchased by the licensee from the licensor was ordinarily excluded from royalty payments.

Estimated total royalties on the airframe portion of the program are shown in Table 15. Based on the royalty payments about which we have specific knowledge, total royalties have been estimated at five percent of the total work performed by Japanese vendors, or \$765 thousand. This figure was obtained from Table 5, which shows that MHI's purchases in Japan were \$21.8 million, excluding the KAC subcontract. Approximately 30 percent of this amount in turn went to purchases from U.S. vendors. For the remaining 70 percent (\$15.3 million), we assume an average royalty payment of five percent.

The unit cost figures shown in Table 15 were obtained by allocating costs (except for the LAI royalty) to approximately 200 airframes. The 200-airframes figure was obtained by adding the 160-unit C-1 program and the 30-unit C-2 program, and assuming that the production of the substantial number of spares in the C-1 program was equal to ten complete airframes.<sup>32</sup>

For the J-79 engine, the important part of the rights payment, \$2.5 million from IHI to GE was for 300 engines on a royalty-free basis. IHI also made royalty payments to certain GE vendors. These were computed from the data in Table 10, assuming there were no royalty charges for IHI domestic purchases that were ultimately supplied by U.S. vendors.

Table 15

PAYMENTS FOR RIGHTS AND TECHNICAL ASSISTANCE IN THE F-104J PROGRAM

(In \$ thousand)

Airframe Technology

Item	Cost per Airframe
Technical assistance .....	20.8 <sup>a</sup>
Manufacturing rights	
Initial payment to LAI .....	7.5 <sup>b</sup>
Royalty to LAI .....	31.5 <sup>c</sup>
Vendors' royalty to LAI.....	3.8 <sup>d</sup>
Total, manufacturing rights .....	42.8
Total, airframe technology ....	63.6

Engine Technology

Item	Cost per Engine
Technical assistance .....	1.1 <sup>e</sup>
Manufacturing rights	
Initial payment to GE .....	10.0 <sup>f</sup>
Royalty payment to GE vendors .	0.8 <sup>g</sup>
Total, manufacturing rights .....	10.8
Total, engine technology .....	11.9

<sup>a</sup>Technical assistance of \$4.16 million/200 airframes.

<sup>b</sup>Payment of \$1.5 million/200 airframes.

<sup>c</sup>Average for the first 160 airplanes.

<sup>d</sup>Estimated as 0.05 x 15.3 million/200 airframes.

<sup>e</sup>Technical assistance of \$0.28 million/250 engines.

<sup>f</sup>Payment of \$2.5 million/250 engines.

<sup>g</sup>Estimated as 0.05 x 4.1 million/250 engines.

For the remainder (\$4.1 million) a five-percent average royalty was again assumed. These charges were allocated to 250 engines, because total production for both C-1 and C-2 programs will approximate that number.<sup>33</sup>

Payments for technical assistance have been allocated in the same

fashion as payments for rights. Japanese vendors received minimal technical assistance from licensors. Those technical assistance programs of significant size were with MHI and IHI.

We are now in a position to examine the direct costs of transfer in relation to total production costs. For this purpose the F-104G costs shown in Table 4 will be used. This U.S.-produced model has an airframe and engine similar to those of the F-104J. According to Table 15, direct costs of airframe technology transfer amounted to \$63.6 thousand per plane, or about 8.1 percent of the total F-104G airframe cost. Direct costs for engine technology transfer were \$11.9 thousand per engine, or about 6.5 percent of the comparable U.S.-produced engine cost. Together these represent about 7.8 percent of the total cost of the airframe and engine.<sup>34</sup>

Technical assistance amounted to more than a quarter of the total direct costs of transfer. LAC officials estimate that about 70 percent of the MHI technical assistance program was spent in overcoming problems posed by language and geography.

#### Indirect Costs

Production costs of items such as aircraft are importantly influenced by the rate of learning and the economies of scale. These factors are in turn determined by the rate of production, the scheduled volume of production, and the delivery schedule. This relationship can be formally stated as

$$C = f(x, V, T, m),$$

where C denotes the cost, x the rate of output, V the scheduled volume

of output,  $T$  the time output begins, and  $m$  the length of the output period.  $T$  and  $m$  fix the production period measured from the time the program begins. Note that there are only three degrees of freedom; specification of any three variables fixes the fourth.<sup>35</sup>

The rate of production is the central variable in the economic literature on costs, while the volume of production is the central variable in the literature on learning or progress curves. Our present concern, however, is not with the total costs of production attributable to each variable; it is how these costs vary with the number of producers in a program, and what costs can be avoided when production responsibility is concentrated in a single firm. To this end we will discuss each variable.

The relationship between costs and the rate of production is traditionally divided into two parts: the relationship between output and investment in plant and equipment (economies of scale), and the relationship between output and variable factors of production (economies of plant utilization). Let us consider investment first. Both Lockheed and Mitsubishi had the factory space and basic equipment required for F-104 production. Few new facilities had to be added in Japan specifically for the program. About \$10.1 million worth of the capital invested in Japanese aircraft capability was designated for the F-104J; private investment accounted for about \$8.4 million of this total. Most of this investment for the F-104J program was for the J-79 engine. IHI invested \$5.3 million and the Japanese Government an additional \$1.1 million in J-79 engine facilities. The airframe portion of the program required only about \$3.7 million in new investment. For all

programs through 1964, including both public and private funds, the total investment was \$47.8 million.

Tooling costs are more easily attributed to a specific program than are plant and facility investment expenditures. Had Lockheed produced the F-104J instead of Mitsubishi, many tooling costs could have been avoided. The extra tooling costs in a co-production program, however, greatly depend on how much tooling is transferred from the original producer. In the T-33A program, for example, the co-producer was a bona fide second source, and almost complete tooling duplication was required as a consequence. In the F-86F program, by contrast, a complete set of tooling was sent from an NAA plant to Mitsubishi. Since this tooling was mostly U.S. Government property that probably would have been scrapped otherwise, however, the extra expense attributable to co-production was mostly for transportation and refurbishing the tooling. The tooling expense attributable to co-production is largely a function of the extent to which production in the new and old locations overlaps.

Precise tooling costs for the F-104J program are unavailable, but a reasonable estimate can be derived from MHI's man-hour figures. MHI invested about 1.5 million man-hours in the original tooling. (Total MHI man-hours for all portions of the C-1 program were about 7.0 million.) The MHI tooling experience appears reasonable when compared with Lockheed's original tooling for the F-104A, about 1.4 million man-hours.

Costing the Japanese tooling expenditure is difficult, but if we use the Japanese aviation industry rule of thumb, which estimates labor costs at \$3 per hour, we arrive at a tooling cost of about \$4.5 million, plus some allowance for overhead and indirect expenses. Added to this figure should be the tooling costs of the other firms in the program,

but little relevant information on that is available. MHI did most of the airframe tooling, and we surmise that the only other major item was the engine tooling, for which no data are available.

The cost for MHI's tooling is somewhat overstated because some personnel destined for work on other parts of the program were put to work building tools. This extra expense is properly regarded as a set-up cost, however.

In sum, as a rough and probably high estimate, we can attribute to the investment costs of the airframe portion of the C-1 program, \$3.7 million for plant and facilities and \$4.5 million for direct tooling labor. Dividing this total by 200 planes yields a unit-fixed-cost of \$41,000.<sup>36</sup> It was noted earlier that Lockheed sold the F-104G airframe for about \$789,000 per copy, and it appears likely that the Japanese could also have bought airframes from LAC for this price. We may therefore conclude that the avoidable fixed cost amounted to a little more than five percent of the airframe cost.

It is important to keep in mind that the present discussion is concerned with the additional expenses attributed to dividing production of an item between two firms, rather than determining the relationship of total cost to the various causal variables. For our purposes, then, the most important consideration is the extent to which tooling can be transferred along with program responsibility, bearing in mind that tooling is designed for a particular range of production rates and volumes. Had the C-1 program been different, Japanese tooling expenditures might have differed from those estimated above. On the other hand, the tool designs provided by Lockheed presumably reflected its planned F-104

production rates and volumes in the United States. The Japanese and U.S. volumes of F-104 production were similar.

More generally, it does not appear that the relationship between the rate of production and tooling costs should importantly affect the costs attributed to dividing production rather than concentrating it within a single firm. The tooling for the original producer would have been designed with some particular rate of production and total output in mind. Transfer of the program to another manufacturer would not affect the total quantity to be bought nor should it affect the rate of production unless the transfer required so much time that the total volume for the program could not be produced with the originally scheduled rate of production. In that case, either the length of the production period would have to be extended or the rate of production would have to be increased. Increasing the rate of production would therefore be a cost attributable to the separation.<sup>37</sup> The important consideration appears to be the impact of separation on scheduling.

The usual view is that the shorter the period between the start of a program and the delivery of the first item, the greater the cost. In a domestic program with a specified volume of production and a specified rate of production, higher costs can be expected if an early target date is established for the first delivery. In international co-production programs, however, the date of first delivery will partly govern the amount and type of imports. The earlier the date of delivery, the more knockdown and component parts will be acquired from the original supplier. The cost impact will depend on the relative costs of foreign and domestic production.

The schedule may affect costs in still another way. The longer the time between the start of a program and the **date** of first delivery, the less hurried the process of transferring the technology can be. The direct costs and effectiveness of transfer may be related to the speed of transfer. Certainly the phase-in process, previously emphasized as a key to successful transfer of learning, is likely to be hindered by a tight schedule. The crucial element here is the effort expended on scheduling and planning. With a fixed production schedule for a program and a fixed quantity to be produced, if any time is lost in transferring production, the rate of output will have to be greater. This will presumably increase the cost of production. The two factors determining the impact of a co-production decision on the relationship between cost and schedule are the time lost in transfer of manufacturing responsibility and the extent that schedules can be adjusted.

Although little can be said empirically about these cost relationships on the basis of the Japanese experience, the F-104J schedule may be of interest. The program was approved April 15, 1960. The first plane was scheduled and delivered at the end of March 1962. The 180th plane was scheduled for the end of January 1965, and delivered the end of March 1965. There was some schedule slippage during the period between these points but only a slight delay in completing the program. The slippage was primarily at the beginning of the program, and partly attributable to the unusual weather in 1963.

This delivery schedule was one of the determinants of the time-phasing of the transfer of manufacturing responsibility from LAC to MHI. The important point is that the transfer was not a single event, but a series of events occurring over a period of time. Time phasing of

transfer means that considerable flexibility is possible in adjusting the transfer of programs and technology to meet delivery schedule requirements. Such adjustment, of course, requires substantial and careful planning, as in the Japanese co-production programs previously discussed, but can minimize the impact of transfer on the rate of production. One can conceive of a time pattern of transfer by which one producer's activities gradually diminish and the new producer's gradually increase, with little effect on the delivery schedule and rate of production.

We are concerned with the cost associated with dividing a single program between two firms, not the underlying determinants of total costs. Consequently, our interest in the influence of production volume centers on the impact of co-production on progress or learning curves. In the consideration of progress curves, as Hirshleifer has pointed out, costs are influenced by two aspects of volume: the actual total output and the scheduled total output.<sup>38</sup> Increasing familiarity with production processes should increase labor-force productivity and thereby progressively lower unit costs.<sup>39</sup> For this effect, it is the actual output that is important. An increase in the scheduled volume of output will lead to different managerial decisions about investment in facilities and tooling and to different production procedures that should also lead to progressively lower unit costs.<sup>40</sup> For this latter effect the scheduled output, rather than the actual output, is significant. For our purposes we need be concerned only with the combined effects.

In analyzing the relationship between co-production and the costs associated with the volume-of-production variable, the central issue is how much learning can be transferred among firms. We therefore need to compare the progress curves of the two co-producers; more precisely, we

would like to know how the relationship between unit cost and the cumulative output for each firm differs, adjustments having been made for differences in the efficiencies of the firms, and their rates of production and delivery schedules.<sup>41</sup>

Two interfirm comparisons of the volume cost relationship are of interest. Assume that the first firm has a total cumulative production equal to  $N$  units. Also assume that the second firm is going to take on a co-production program of  $n$  units. One comparison is between the cost of the original producer's first  $n$  units and the second firm's costs for  $n$  units. This comparison indicates (assuming all adjustments for other cost effects have been made or that the firms are equally efficient) the extent to which the first firm's learning was transferred to the second firm.

The second comparison is between the cost of  $n$  units produced by the new manufacturer and the cost of units  $N$  to  $N + n$ , had they been manufactured by the original producer. This comparison indicates the cost impact of splitting the production run between two firms. The comparisons will be considered in order.

For the first comparison, if the two firms have identical progress curves, no learning has transferred. If the licensee's unit cost is lower for the first unit than that experienced by the first producer, or if his curve shows a steeper "slope,"<sup>42</sup> then some learning has been transferred. If the new firm's initial unit cost equals the licensing firm's unit cost at the time of transfer, and if the slope of the progress curves for both firms from that point on is the same, all learning has been transferred.

Figure 2 illustrates these relationships. Following the usual practice in progress curve measurement, the figure shows direct labor hours per aircraft as a function of total number of units produced. The line A-A represents the licensor's progress curve. Assume that a co-production program is established at point X after ten units have been produced by the licensor. If all of the licensor's learning has been transferred, the licensee's manhour requirements for his first unit will correspond to those needed by the licensor for the eleventh unit. This ten-unit advantage would remain with the licensee throughout his production. This situation is shown by the progress curve B-C, which approaches the licensor's curve asymptotically. Of course, if none of the licensor's learning is transferred and interfirm differences are ignored, then the licensee's progress curve will be identical to that of the licensor.

In most programs, some but not all of the licensor's learning will be transferred. Thus, the licensee's initial position will lie somewhere between A and B. Moreover, the slopes of the two curves may or may not converge in the manner shown, depending on differences in efficiency and factor prices which have been ignored for the sake of illustration. The important point, however, is that learning-transfer results in the new producer requiring fewer manhours for his initial production than was required by the original producer.

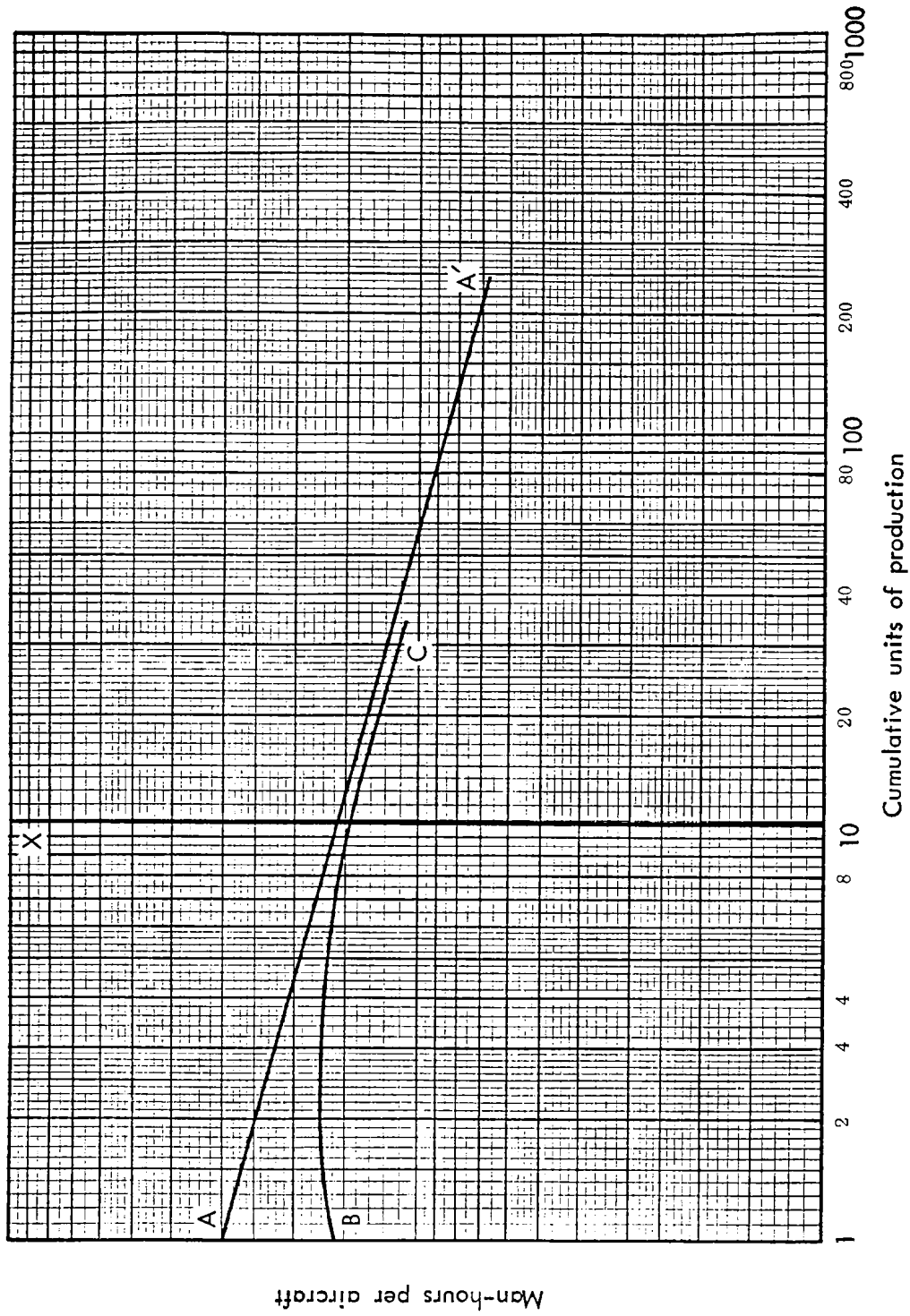


Fig. 2—Progress curve example

Let us examine the F-104J in this manner. Early in the program, LAC officials made estimates of the direct manufacturing man-hours required by MHI and KAC. LAC officials stationed in the Japanese plants observed that these early estimates conformed reasonably well to the actual man-hour expenditures of the two firms. Although these early estimates have some speculative aspects, they provide a basis for quantitative estimates of the amount of learning actually transferred.

In order to compare the Japanese and U.S. experience, some data had to be adjusted in the following manner: we know that a number of airframe items were manufactured in the United States, and some were purchased from Japanese vendors; both these factors must be accounted for. We estimate the price of that part of the airframe produced at Lockheed, which excludes equipment-purchase items, to be about \$520 thousand, or roughly two-thirds of the total airframe costs shown in Table 4. Imports of hardcore airframe shown in Table 5 accounted for approximately \$38 thousand per airframe. LAC officials estimate total imports of airframe items to be approximately \$50 thousand per airframe. This, plus an estimated \$40 thousand for airframe purchases from Japanese vendors, shows us that approximately 17 percent of the total airframe effort was performed outside of the MHI and KAC facilities. As shown in Table 16, we can now estimate the total direct man-hours as 21 percent more than the amounts actually spent by MHI and KAC.

The Japanese data are now in a form that can be compared with Lockheed experience. Choosing the LAC base is difficult, however. Our choice is the first 160 F-104As and F-104Cs. However, the F-104J airframe was at least twenty percent heavier and in other ways differed

from the U.S. versions. Indeed, on a cost-per-pound basis, as progress curves are sometimes expressed, the Japanese experience would be much more impressive than on the cost-per-plane basis used here. The Lockheed production of F-104Gs or F-104J knockdowns might also be introduced, but it would be difficult to adjust the data for learning accumulated from previous models or for the assembly operations not performed. Consequently, we have preferred to use the F-104A, C for the comparison even though doing so may understate the U.S. cost relative to the Japanese cost. This means that any statistical biases are in the direction of understating the interfirm transfer of learning.

LAC and MHI progress curves are shown in Table 17. For the first ten F-104s produced by each firm, MHI used substantially fewer man-hours than did LAC. The LAC man-hour rate per plane was slightly less than the MHI rate per plane by the time each had completed 160 aircraft. Direct man-hours used for the first 160 airframes by the Japanese were only about 90 percent of the total LAC man-hours for the first 160 F-104s built in the United States.

The relationship between the two learning curves is shown in Fig. 3. The rate of learning in Japan (85-percent slope) is well below the U.S. rate (78-percent slope). However, the lower cost in Japan for the first units meant that the total Japanese man-hour expenditure was lower than Lockheed's expenditure for the first 160 planes it produced.

Note that average man-hours per plane for the first 160 produced by each firm were 43.0 thousand for MHI and 47.4 thousand for LAC.

We are now in a position to answer the first of our two questions: How much learning was transferred from LAC to MHI? If we assume that

Table 16

DIRECT MAN-HOURS, MANUFACTURING;  
160 F-104J AIRFRAMES

(In millions)

MHI .....	3.98 <sup>a</sup>
KAC .....	1.71 <sup>a</sup>
Other .....	1.19 <sup>b</sup>
Total .....	6.88

<sup>a</sup>Estimated by officials of  
LAI.

<sup>b</sup>Estimated at 21 percent of  
the total MHI and KAC man-hours.  
Total outside work was approxi-  
mately \$90 thousand per unit.  
Exclusive of equipment purchase  
items, LAC airframes cost about  
\$520 thousand, and  $90/(520-90) =$   
21 percent.

Table 17

COMPARISON OF U.S. AND JAPANESE DIRECT MAN-HOURS, MANUFACTURING

(In thousands)

Aircraft	First U.S. Program, F-104A,C	First Japanese Program, F-104J
Numbers 1-10 (average)	101.0	76.4 <sup>a</sup>
Numbers 150-160 (average)	30.5	33.1 <sup>a</sup>
Numbers 1-160 (total)	7590.0	6880.0

<sup>a</sup>Based on LAI estimates of MHI direct man-hours,  
inflated by the ratio of total Japanese man-hours  
to MHI man-hours shown in Table 35 ( $6.88/3.98 = 1.73$ ).

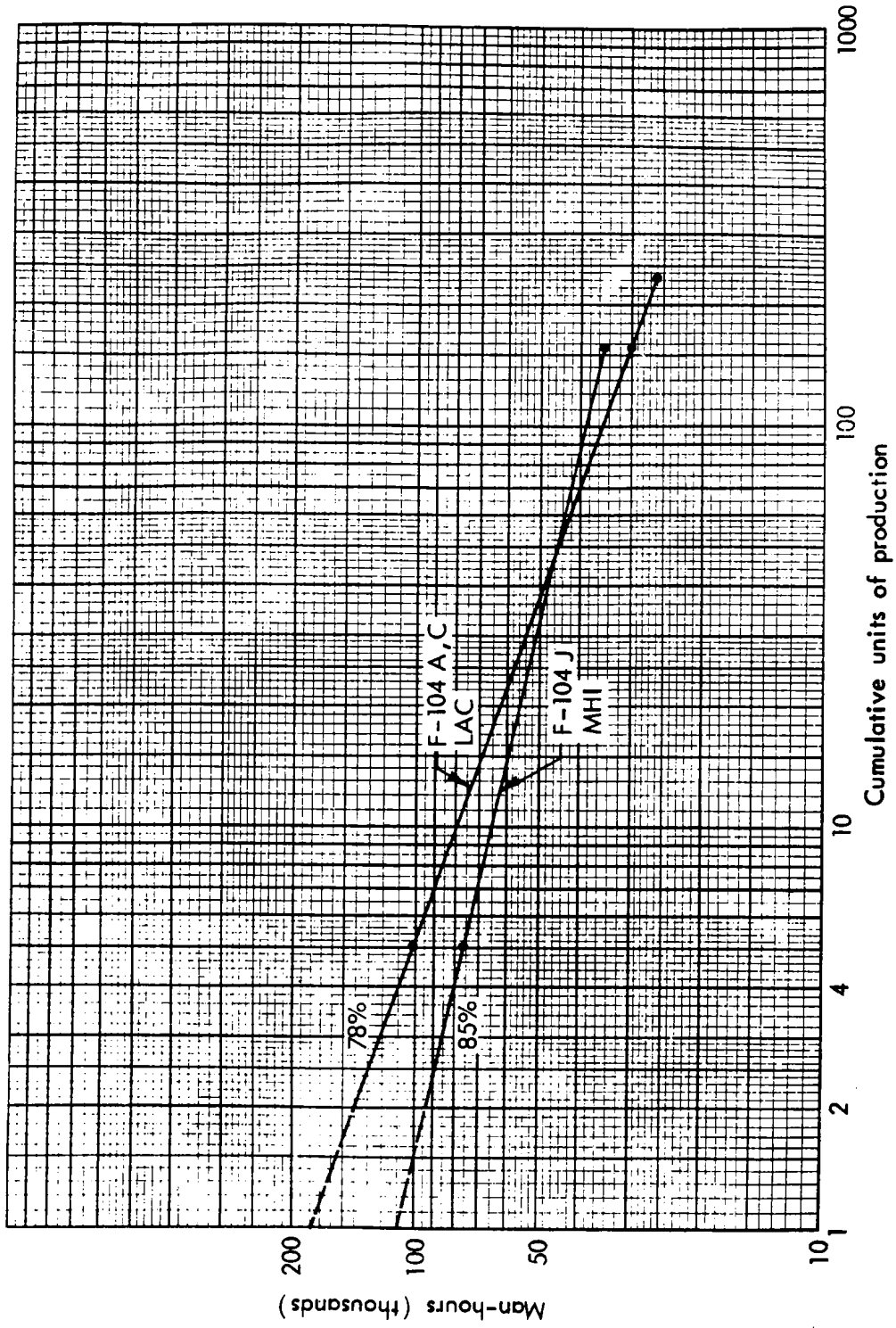


Fig. 3 — F-104 progress curves

the firms were equally efficient and that the rate of production and delivery schedule did not affect man-hour improvement, some summary estimates can be made.

One measure would be to assume that in the absence of a transfer of learning, MHI would have had the same man-hours for the first unit as LAC had for its first unit. Actually, MHI's figure was about 25 percent lower, or about the number of man-hours LAC used to produce the fourth plane.

On the other hand, one might take the entire 160-plane program as the basis. Since the rate of improvement for MHI was less than for LAC, this gives a lower figure. Total Japanese man-hours were about 10 percent less in this case. The higher estimate of the amount of learning transferred seems the more reasonable one, considering the nature of the Japanese labor system, which results in high factory manning levels.

The reasons for accepting the higher estimate stem from Japanese employment practices and labor costs. It was pointed out before that international man-hour comparisons should be made with caution because of the structure of the Japanese economy. The present comparisons seem valid to us because the biases are all in the direction of understating the amount of learning transferred. Put another way, the direction of the bias seems to justify comparisons of U.S. and Japanese man-hours, provided the results are interpreted as conservative estimates.

Employment by a large Japanese firm implies a lifetime commitment. Therefore, one often observes more labor hours per unit of Japanese output than are technically required, or than are typically observed in the United States. Probably more important, there are large differences in wage rates between the United States and Japan. Differences by a factor

of three are not uncommon in the "blue collar" aerospace skills. Capital equipment is, if anything, more expensive in Japan, so it is not surprising that the Japanese tend to use larger work forces to reduce idle equipment time. In general, because of different factor prices, we would expect the Japanese to use more labor-intensive processes than do U.S. firms.

All of these considerations imply that more man-hours per plane would be expended in Japan than in the United States, regardless of the amount of learning transferred.<sup>43</sup> Therefore, since this bias works against an empirical demonstration of the transfer of learning, we feel our international comparison is permissible. The results should be interpreted with these difficulties in mind, however.

In short, it appears reasonable to conclude that a substantial amount of learning was transferred -- enough so that the man-hours used on the first MHI F-104 were 25 percent less than those required for the first LAC F-104. For the program as a whole, the learning transferred saved MHI about 10 percent of the man-hours required by LAC for its first 160 aircraft.

Addressing the second comparison, i.e., between the man-hours used by MHI and those that would have been required had the 160 F-104Js come off the LAC assembly line, the problem is to compare the total MHI man-hours for 160 aircraft (6.9 million) with the total LAC would have required to produce an additional 160 aircraft. Based on very limited data about the F-104G, the total output by LAC of all F-104 models at the time of transfer, and LAC's rate of learning discussed earlier (78 percent), we estimate that total LAC man-hours for an additional 160 aircraft would have been 3.7 million, or about 23 thousand man-hours per plane.

On this basis it appears the MHI man-hours were nearly twice what LAC would have required.<sup>44</sup>

Even if Japanese production did require perhaps twice as many man-hours, total labor costs appear to have been lower. While international comparisons with Japanese labor rates are tricky, knowledgeable Japanese officials believe that a good order of estimate might be about one-third the U.S. rates. On the basis of the total cost data for the F-104J program, this estimate appears slightly high, or else our estimate of the man-hour requirements is slightly high, or most likely, both are high. Nonetheless, the total cost figures to be discussed shortly indicate that as orders of magnitude, these estimates are credible.

This discussion of the relationship between costs and the total volume of production has yielded two results. The first is that a substantial portion of the learning embodied in LAC's progress curve was transferred to MHI. This transfer can be seen by comparing the man-hour experience for the first 160 planes produced by each firm.

The second result is that although more man-hours were required to produce the F 104 in Japan than would have been required had the plane been purchased off the Lockheed production line, the labor cost was less because of differences in wage rates.

The indirect expenses associated with co-production of the F-104J have been analyzed by examining three variables: the rate of production, the delivery schedule, and the volume of production. Let us briefly review the major findings.

The investment required to support production at the scheduled rate was relatively low, about \$3.7 million for the airframe and about \$6.4

million for the J-79 engine. The airframe investment was low because facilities had been acquired for previous programs. Tooling required about 1.5 million man-hours, with direct labor costs estimated to be about \$4.5 million.

The cost impacts associated with the delivery schedule cannot be quantified with available data. The delivery schedule influences decisions about which items to produce locally and which items to import. The delivery schedule also influences the speed of transfer of technology, which in turn presumably influences costs. The important point here is that transfer of technology is not an all-or-nothing decision or a one-time event. The Japanese co-production programs featured a phase-in of Japanese responsibility so that both the amount of technology transferred and the timing of the transfer could be adjusted in accordance with delivery schedule requirements.

The indirect cost of co-production resulting from dividing the total volume of production between two firms is particularly interesting. An important issue is the loss of progress curve advantages. A significant finding about the F-104J program is that a sizable fraction of Lockheed's learning was transferred to Mitsubishi. The result was that MHI's man-hours for the first F-104 it produced were 25 percent less than LAC's man-hours for its first F-104. Total MHI man-hours for the whole program were about 10 percent less. These figures compare LAC and MHI's first production experience. For measuring the indirect costs of co-production, the relevant comparison is between MHI's actual experience and LAC's hypothetical experience had it produced the aircraft. For this comparison it appears that MHI used about twice as many man-hours as LAC would have used. This quantity difference was more than counterbalanced by the difference in hourly labor costs.

Total Cost of Production

Let us now examine the total cost of F-104Js to the Japanese Government, and compare it with the price Japan might have paid for finished airplanes in the United States.

It is well known in aerospace circles that the Japanese co-production programs required more man-hours than would have been required in the United States. It is also well known that certain parts and materials produced in Japan cost more than their U.S. counterparts. Furthermore, some investment and set-up costs were incurred that could have been avoided by purchasing from a "hot" production line. As a result, it has been commonly assumed that the Japanese planes cost more than they would have in the United States. The usual discussion of these programs has centered on the question of whether the Japanese gained enough benefits to offset the premiums they paid. Estimates of the premium for the F-104J have ranged from 20 to over 100 percent. The actual cost data for the F-104J program confute these common notions, however.

In fact, no premium was paid. The Japanese obtained the planes at a lower cost than they would have paid in the United States.

The high materials costs for the F-104J program appear to have been more than offset by the lower labor costs in Japan. While it is impossible to estimate precisely the impact of the differences in factor prices, the figures in Table 17 indicate that the factor-cost saving must have been large.

Table 18 shows the Japanese cost for an airframe to be \$620 thousand, as against a U.S. cost of \$789 thousand for an F-104G bought in

Table 18

COMPARISON OF U.S. AND JAPANESE AVERAGE UNIT  
PRODUCTION COSTS FOR F-104 AIRCRAFT

(In \$ thousand)

Item	Japanese Production (160 F-104J Aircraft)	U.S. Production (F-104G MAP Aircraft) <sup>a</sup>
F-104 airframe <sup>b</sup>	620 <sup>c</sup>	789
J-79 engine	232 <sup>d</sup>	184
Total	852	973

<sup>a</sup>Data taken from Table 24.

<sup>b</sup>Includes all items of installed equipment other than electronics.

<sup>c</sup>Includes payments to Lockheed for technical assistance, tools, data, and cataloging shown in Table 21, allocated to 200 airframes.

<sup>d</sup>Includes payments to General Electric for technical assistance shown in Table 21, allocated to 250 engines.

smaller lot sizes. For the engine, the Japanese cost was higher -- \$232 thousand compared with \$184 thousand. Adding these two totals gives an F-104J unit cost of \$852 thousand -- about seven-eighths the U.S. price of a comparable plane.

The Japanese costs include technical assistance (\$20.8 thousand for airframe, \$1.1 thousand per engine); rights (\$42.8 thousand per airframe, \$10.8 thousand per engine); tooling and start-up costs (direct costs were about \$41 thousand per airframe); and all other manufacturing costs. The only identifiable cost not included is the fixed investment for the program; it was omitted because LAC had some Government-furnished plant and equipment, and its facilities were used on programs other than the F-104. Therefore, it was not clear what the corresponding figure for the United States should be. Even leaving the F-104J costs unadjusted, however, and

allocating all fixed investment earmarked for the F-104J program, the basic conclusion remains the same. Allocating the investment would increase the airframe cost by \$23 thousand and the engine cost by \$32 thousand. This total increase of \$55,000 would give a total figure for the F-104J of \$907 thousand. This is still approximately 10 percent below the price Lockheed charged for the F-104G.

Electronics are not included in Table 18 for two reasons. First, they were not co-produced in Japan during the C-1 program, certainly not in the sense that airframes and engines were co-produced. Second, the J and G versions of the F-104 differ substantially in electronics, even though the planes are essentially identical in terms of airframes and engines. Since the C-1 electronics were imported, they do not affect the cost comparison.

It was startling to discover that the Mitsubishi F-104J cost less than a Lockheed F-104J would probably have cost, since we had heard much about the high cost of parts and materials for the F-104J program. The conclusion, however, seems clear. As shown in Table 18, an F-104 airframe produced in Japan cost only 78.6 percent as much as an airframe produced in the United States. Indeed, the unit cost estimate of \$620 thousand for the Japanese plane is slightly exaggerated because all of the costs for technical assistance, tools, etc. were charged entirely to the 160 aircraft in the C-1 program, rather than also being allocated to the spare parts and 30 aircraft of the C-2 program. Although differences in factor prices tend to cloud the issue, and quite apart from any beneficial effects to the Japanese aviation industry, the decision to co-produce the airframe was economically advantageous for Japan.

On the other hand, the cost of producing the J-79 engine for Japan for the C-1 program was higher than in the United States. U.S. costs were only about 79.3 percent of the Japanese costs. This relationship, which confirms the common view about the relative costs of U.S. and Japanese engines, is probably due to the large proportion of imported items entering the engines produced by IHI. Imports for the C-1 engine program were considerably more important than for the airframe part of the C-1 program.

The conclusion is simple but impressive. The Japanese did not pay a premium to produce the F-104J in Japan. Even under a conservative allocation of costs, the unit cost of the Japanese-produced planes was less than LAC's price for the F-104G.

#### Benefits of the Co-Production Program

Although our primary interest is in the process and costs of transferring U.S. aerospace technology to Japan, it would be remiss not to note the benefits to sponsors of these transfers. Both the United States and Japan enjoyed benefits from the co-production arrangements that would not have been realized from alternate ways of providing the Japanese self-defense forces with aircraft. Let us consider the Japanese side first.

A country seeking new weapons for its military has three alternatives. It can buy the items from a foreign manufacturer, it can design and produce its own systems, or it can engage in co-production. Many countries object to the importation of weapons even if comparative economic advantages favor foreign producers. The arguments for national self-sufficiency in weapons are several and diverse.

Domestic production, it is argued, simplifies maintenance and operational support of military equipment, and assures a wartime supply. A recent and highly popular argument is that there are important technological and economic spill-overs to the other sectors of the economy from military technology. Furthermore, local production of weapons may be desired for balance-of-payments reasons. This factor has become increasingly important as international trade in weapons has changed from primarily grant-aid to cash sales.

All these arguments involve military or economic considerations. Powerful political forces often lead to a desire for local weapon production; or perhaps it is more correct to say that local weapon production is frequently a politically feasible way to achieve some economic or military goal. Foreign-produced weapons do not have the same political implications as nationally produced weapons. Importation of military hardware can jar nationalist sensitivities and arouse feelings against the country of origin. Local production also attracts the support of the business community.

These factors were crucial in the Japanese case. The Japanese Government (and the U.S. Government) desired an increase in the capabilities of the Japanese self-defense forces. This was -- and is -- an extremely touchy political issue in Japan. Co-production, from a political point of view, was part of a package that made the Government's defense policies politically acceptable to the Japanese. The fact that the Japanese regard the F-104Js produced in Japan as Japanese -- not U.S. -- airplanes explains many of the political benefits of co-production.

If a nation chooses not to import military hardware, it still must decide whether or not to develop its own weapons. Development is so expensive that many smaller countries regard it as prohibitive, especially for technically advanced systems, though Japan's interest in developing transports and trainers indicates that even countries with small aircraft industries may find some types of development activities attractive.

Other countries attempting to design advanced weapons have had various fortunes. France, for example, seems to have been more successful in recent years than England. Co-production is a way of acquiring at least some of the benefits of a domestic weapon system industry without the expenses of development. The country obtains the maintenance, operational support, and supply-assurance advantages of a local industry. Whether or not there are the same technological spill-overs is more debatable. If the spill-overs occur from the process of conducting R&D on highly advanced systems, then clearly co-production does not provide such advantages. But if the spill-overs result from familiarity with manufacturing and using systems involving advanced technologies, then co-production does have some of the same advantages as domestic development.

When considering spill-overs, it is also relevant to ask about the contribution of co-production to the technology base of Japan's industry. By the time co-production started in Japan, the technological innovations embodied in the systems produced were between five and ten years old. This has led some observers to regard the Japanese co-production programs as of limited technological value.

The technology Japan received would have been little help had it wished to engage in design work on the frontiers of aerospace science and engineering. This was not Japan's interest, however. Japan's design objectives have been commercial aircraft and military transports and trainers. Advanced technology is less important for this purpose; ten-year-old information often suffices. This can be seen by examining the YS-11 and the MU-2, both of which incorporate components or design features of the systems produced by co-production arrangements. A country interested in commercial results will probably do better to explore well-traveled areas rather than the frontiers of aeronautical science. Co-production arrangements for less sophisticated products may provide quite adequate technological spill-overs.

From the U.S. point of view, the major benefit of military co-production programs is political. It permits the use of local economic and political pressures to achieve mutual defense goals. When the United States wants its allies to increase their defense capabilities or bear more of the expense of a defense posture, U.S. arguments may be more persuasive if the allies themselves can produce the hardware. The U.S. goals of economic development in other countries may also be furthered by encouraging a local defense-goods industry. The United States, moreover, reaps some benefits from the maintenance and operational facilities available in other countries as a result of their production activities.

The United States has participated in many co-production arrangements and has promoted and participated in other international aerospace programs such as joint ventures in R&D. In spite of this history, present DOD policy is to promote direct military sales rather than grant-aid or co-production arrangements, primarily because sales do more to

ease the U.S. balance of payments problem. This preference is also supported by critics of co-production, who claim that it results in a higher cost for weapons than do purchases from the United States. It is instructive to examine both the balance of payments and cost considerations in light of the F-104J experiences.

Outright sale of military hardware obviously has a more beneficial impact on the U.S. balance of trade than has any other type of arrangement that supplies a country with weapons, if the type and quantity of weapons to be acquired are independent of foreign exchange requirements and other financial considerations. Rarely does this independence exist. At the time of the F-104J procurement, Japan faced severe foreign exchange limitations -- to the extent that complete reliance on imports would almost surely have led to either a reduction in the size of the program, or a larger financial contribution by the United States.

If we look for a moment solely at the impact of co-production on the U.S. balance of payments, the disadvantage may not be as large as often supposed. For the F-104J program, for example, in addition to the \$75 million the United States contributed to the program -- all of which was spent in the United States -- we estimate that about \$88.7 million of the Japanese contribution was also spent in the United States (see Table 19). This amount spent is more than 45 percent of the total Japanese contribution. In other words, the F-104J program yielded a net addition to U.S. exports, and therefore in our favor in the balance of trade, of nearly \$90 million.

After examining the relative costs of co-produced and U.S.-produced weapons, we believe the cost penalties associated with co-production have been exaggerated. During this study, we were told repeatedly that the

Table 19

IMPACT OF F-104J CO-PRODUCTION ON THE  
U.S. BALANCE OF TRADE: C-1 PROGRAM<sup>a</sup>

Japanese Imports in \$ Million

Item	Amount
Airframe imports	
MHI direct .....	13.9
MHI vendors <sup>b</sup> .....	6.5
KAC direct .....	3.5
KAC vendors <sup>b</sup> .....	2.1
Engine imports	
IHI direct .....	22.8
IHI vendors <sup>b</sup> .....	5.9
Electronics imports	
MHI <sup>c</sup> .....	23.4
GFAE (JDA) <sup>d</sup> .....	<u>10.5</u>
Total .....	88.7

<sup>a</sup>Includes only purchases from the United States out of the Japanese contribution to the program.

<sup>b</sup>Estimated at 30 percent of total vendor receipts.

<sup>c</sup>MHI purchased 110 complete sets of electronics from U.S. suppliers.

<sup>d</sup>Estimated at 76 percent of total sales to JDA, the average shown in Table 23 for three leading electronics suppliers.

Japanese-produced aircraft had cost much more than the U.S.-produced aircraft; some estimates of the additional costs ranged from 30 to 100 percent.

The tendency to exaggerate these costs appears to be due to the higher cost of certain items in Japan than in the United States. It is true that parts and materials cost substantially more there. It is also true that only a part of the licensor's progress curve advantages are

transferred. When we look at system costs as a whole, however, including labor cost advantages and the effects of some learning transfer, we see that some large savings may cancel out some of the higher costs. It is not at all obvious from a study of the costs of co-production that past programs have incurred the penalties that many, even experts on international aerospace affairs, believe were paid. As mentioned above, we found the F-104J cost to be no more than that of an F-104G produced in the United States, and probably about 10 percent less.

## VI. CONCLUSIONS

This study has described the process and costs of transferring manufacturing technology from U.S. to Japanese aircraft producers. The basic transfer techniques followed the same pattern in all programs. The Japanese co-producers were furnished legal rights, manufacturing drawings, tool design information and, in some instances, actual tooling. Their U.S. counterparts also supplied planning and process information, technical assistance teams, and some back-up manufacturing capability.

The costs incurred in transferring the technology were both direct and indirect. Direct costs include royalties, technical assistance payments, and similar expenses. Indirect costs occurred because some economies of scale and progress curve advantages are lost when production responsibility is transferred.

Analysis of the F-104J costs showed that the direct costs of transfer made up only a small fraction of the total program costs. Nor were the indirect cost effects as large as might be expected, apparently because Lockheed transferred a significant portion of its accumulated learning on the F-104 to Mitsubishi. Because U.S. firms were paid for data, data rights, and technical assistance, they had clear incentives to provide Japanese firms with the fruits of U.S. experience. Also, some of the progress curve advantages were no doubt embodied in the tooling or tool design information provided by the U.S. firms.

It would be wrong, however, to leave the subject here. This co-production experience has important policy and theoretical implications. On the policy side, two important implications emerge.

One implication of this study concerns military and economic assistance programs and the relationship between the two. In the case of the F-104J, Japan acquired the economic benefits of production experience without additional costs; that is, the aircraft they acquired cost no more than they would have paid for U.S.-produced aircraft. But Japan garnered even richer rewards. Co-production enabled Japan to develop a small but advanced industry that is now moving into design work and production of commercial aircraft for sale in the world market. Politically, co-production helped the Japanese Government gain popular approval of its defense policies -- a gratifying result for the United States as well, which desired expansion of Japan's air defense capability. This probably would have been a much more doubtful issue if the planes had not been produced in Japan.

Co-production may have a number of important advantages denied to other military assistance arrangements. Unlike grant-aid, co-production has the recipient country share the financial burden. Unlike direct military sales, it has much greater economic and political acceptability because the weapons are locally produced. These advantages should not be overlooked simply because of United States concern with its balance of payments. While direct military sales have the most favorable immediate impact on the U.S. balance of trade, it is important to note that purchases from U.S. firms by Japanese contractors, subcontractors, and vendors resulted in very considerable U.S. sales and attendant balance-of-trade benefits. Moreover, when foreign exchange limitations are involved, as they usually are, it is unrealistic to argue that direct sales are more advantageous than co-production. In the F-104J program,

the United States enjoyed about as much benefit as possible. The realistic alternative would have been direct sales of a smaller number of aircraft, resulting in either a smaller defense force or additional U.S. grant-aid to make up the difference.

The methodological implications perhaps merit the most emphasis. After years of neglect, diffusion of technology is coming to occupy an important role in economic theory. Empirical research still lags behind, although recent studies have confirmed the feasibility and fruitfulness of detailed empirical investigation of international flows of technology. It does not appear that more elaborate theoretical models or new techniques will be required. What is involved here is a market phenomenon -- sales of technology embodied in various forms. Transfers of technology can be analyzed with the same tools, problems, and benefits associated with studies of market-directed flows of other goods and services. Particularly in view of the rapid growth in international trade in technology, study of these market phenomena deserves very substantial attention.

FOOTNOTES

<sup>1</sup>The historical literature is surveyed by J. J. Murphy, "The Transfer of Technology: Retrospect and Prospect," in D. L. Spencer and A. Woroniak (eds.), The Transfer of Technology to Developing Countries, Washington, D.C., 1966, pp. 8-36.

<sup>2</sup>The variety of terms in the literature attests to the recentness of interest in the phenomenon; yet it has figured in numerous and diverse investigations, as the following examples illustrate:

J. N. Behrman, "Promoting Free World Economic Development Through Direct Investment," American Economic Review, May 1960, pp. 271-281; W. Gruber, D. Mehta, and R. Vernon, "The R&D Factor in International Trade and International Investment of United States Industries," Journal of Political Economy, February 1967, pp. 20-37; S. Hirsch, Location of Industry and International Competitiveness, London, 1967; D. B. Keesing, "The Impact of Research and Development on United States Trade," Journal of Political Economy, February 1967, pp. 38-48; E. Mansfield, Industrial Research and Technological Innovations: An Econometric Analysis, New York, 1968; R. R. Nelson, International Productivity Differences in Manufacturing Industry: Problems with Existing Theory and Some Suggestions for a Theoretical Restructuring, The RAND Corporation, P-3720, November 1967; R. R. Nelson, M. J. Peck, and E. D. Kalacheck, Technology, Economic Growth and Public Policy, Washington, D.C., 1967; D. L. Spencer, "An External Military Presence, Technological Transfer, and Structural Change," Kyklos, 1965, pp. 451-474; D. L. Spencer, Military Transfer of Technology, Washington, D.C., 1967; R. Vernon, "International Investment

and International Trade in the Product Cycle," Quarterly Journal of Economics, May 1966, pp. 190-207; U.S. Department of Commerce, Technology and World Trade, Washington, D.C., 1967, pp. 119-143.

<sup>3</sup>An outstanding study of this type is: J. Baranson, Manufacturing Problems in India, Syracuse, 1968.

<sup>4</sup>For more discussion of co-production and more data on these programs, see G. R. Hall and R. E. Johnson, Aircraft Co-Production and Procurement Strategy, The RAND Corporation, R-450-PR, 1967.

<sup>5</sup>See also Spencer, Military Transfer of Technology, for a discussion of this subject.

<sup>6</sup>Nelson, Peck, and Kalachek contains a valuable discussion of this subject.

<sup>7</sup>Technology is knowledge or information that permits some task to be accomplished, some service rendered, or some product produced. Conceptually, technology can be distinguished from science, which organizes and explains data and observations by means of theoretical relationships. Technology translates scientific relationships into "practical" use. In practice this conceptual distinction is sometimes blurred. This study, however, is concerned with information sufficiently practical in nature so that there is no problem in referring to it as technology as distinct from science.

<sup>8</sup>In the past, personal contact has been the traditional method of technology diffusion. Although there is no firm information on the point, casual observation suggests that personal transfer is becoming relatively less important, and diffusion by the transfer of physical items relatively more important. This perhaps reflects the complexity of modern technology.

<sup>9</sup>There is considerable literature on international diffusion of information in the process of economic development. See, for example, C. A. Anderson and M. J. Bowman (eds.), Education and Economic Development, Chicago, 1965. (Many of the papers in the volume directly deal with the international flow of knowledge and particularly with Japanese experience.) However, the distinction among general, firm-specific, and system-specific technology is not common in the literature on economic development. We believe this distinction is helpful in understanding the process of technology acquisition.

<sup>10</sup>The relationship between technology and market structure has usually been analyzed by focusing on two issues. One is whether certain market structures are more favorable than others to the generation of inventions and innovations. (For an example, see Nelson, Peck and Kalacheck, pp. 66-88.) The other is the extent to which the present organization of industries -- the number of firms, their absolute and relative sizes, their vertical integration, and so forth -- are the result of technical requirements. (See J. S. Bain, Barriers to New Competition, Cambridge, Mass., 1956, pp. 1-41, 144-146.) Insights into both issues can be obtained by examining the process of technology diffusion, though these subjects have seldom been approached in this fashion.

<sup>11</sup>This discussion abstracts from uncertainty, although in international markets characterized by imperfect information, uncertainty is a vital determinant of the extent, nature, and cost of technology transfers. For a discussion of this see Y. Aharoni, The Foreign Investment Decision Process, Cambridge, Mass., 1966.

<sup>12</sup>On the technology transfers during this period, see Spencer, Military Transfer of Technology.

<sup>13</sup>A tool is "mastered" by checking its compatibility with the aircraft it is used to align. Master tools or gauges are used to locate specific points on the airframe for the purpose of maintaining or checking the accuracy of the production.

<sup>14</sup>The magnitudes and types of special tooling required to produce a plane can be illustrated by the P2V-7 program. Seven different classes of items were involved. The first comprised the 27 master tooling gauges used to maintain interchangeability. The second class was model parts. Approximately 320 parts were provided as references, but not masters. The third class was paper masters -- simple tool design sketches that define within close tolerances the points of interchangeability. The fourth class was standard tooling. Samples of these were furnished. Samples were also furnished for the fifth class, hand tools of mechanics. The sixth class was glass cloths. Glass cloth reproducible layouts of all flat templates, assembly templates, and production templates were provided. Almost 18,000 of these were sent. The seventh class was plaster splashes. Almost 700 master plugs and splashes for drophammer

and stretch dies were made from LAC mockups and dies. These assured proper contour coordination between Japanese-made tooling and parts and assemblies furnished by Lockheed. (U.S. Navy Contract NOas 58-637-c, April 12, 1958, pp. 7-8.)

<sup>15</sup>For a penetrating analysis of the relationship between extent of domestic production and cost, see Baranson, Manufacturing Problems in India.

<sup>16</sup>About 70 percent of the airframe by weight was manufactured by Mitsubishi and about 30 percent by Kawasaki. In dollars, the percentages were 80 and 20. J. Horikoshi, "F-104J Production Program as Viewed from the Japanese Standpoint," AIAA paper 65-804, presented at the American Institute of Aeronautics and Astronautics Meeting, Los Angeles, California, November 15-18, 1965.

<sup>17</sup>For a description of the F-104G and the consortium co-production program (including Germany, Belgium, Italy, and the Netherlands), see "Four Countries Build the Super Starfighter," and "F-104G: A Much Discussed Weapon," both in Interavia, Vol. 18, August 1963, pp. 1192-1200; and E. Vandevanter, Jr., Coordinated Weapons Production in NATO: A Study of Alliance Processes, The RAND Corporation, RM-4169-PR, November 1964.

<sup>18</sup>The U.S. Government contribution covered, in addition to airframe development, part of the cost of the development of NASARR. Only the development work required to modify the NASARR G version to the J version was to have been charged to the Japanese. Program overruns led the Japanese to question whether or not some of their funds defrayed basic R&D efforts.

<sup>19</sup> Although payment for technical assistance in some co-production programs includes parts and materials furnished by the licensor, it did not for the F-104J. All items were purchased under separate procurement contracts.

<sup>20</sup> Horikoshi, p. 3.

<sup>21</sup> Ibid., p. 8.

<sup>22</sup> "Four Countries Build . . .," p. 1194.

<sup>23</sup> Produced under a Turco Products, Inc. license.

<sup>24</sup> Produced under an English Electric Company (NAPIER) license.

<sup>25</sup> Horikoshi, p. 7.

<sup>26</sup> The MHI figure for the KAC subcontract differs in Table 5 from the total of the KAC column because it includes the cost of KAC's assembly activity for the 20-aircraft assembly-only portion of the program.

<sup>27</sup> Japan was also limited in five-axis milling, precipitation hardening, phosphate finishing, and nitriding.

<sup>28</sup> In addition to this assembly work, Mitsubishi Electric has been engaged in a product improvement program for the NASARR. Five of their changes in the NASARR design had been accepted by JDA as of November, 1965.

<sup>29</sup>One suspects Horikoshi had such items in mind when he cited the development of a domestic source to assist operation and maintenance of the weapon system as one reason for selecting items for Japanese manufacture.

<sup>30</sup>Excluding technical assistance, fees for rights are obviously private costs, incurred by the licensee, but are they social costs as well? In the sense that granting manufacturing rights involves no sacrifice of the licensing country's resources, the fees do not become a social cost. But in the sense that fees reimburse the owners for forgoing their rights -- that is, owners of knowledge who have the right to protect and retain that knowledge without disclosure under the U.S. property system -- then such fees become a social cost.

<sup>31</sup>The T-33A license called for an initial fee of \$1 million and a royalty of \$10,000 per plane. The F-86F agreement was more complicated. The initial fee was \$1 million, with a royalty of \$5,750 per aircraft for the first 70 and \$9,500 thereafter. There was a corresponding royalty on spares of three percent and six percent. MHI was permitted deductions for parts and components procured from NAA, subject to a minimum total royalty per plane of \$5,750.

<sup>32</sup>The 20 F-104DJs and the 20 F-104Js supplied in the form of knockdowns have been excluded. Because there was little or no Japanese production for these parts of the C-1 program, it is inappropriate to allocate royalties, license fees, etc. to these planes.

<sup>33</sup>No figures are presented for the electronics part of the program, since it is not clear how much technology or what type of technology was transferred.

<sup>34</sup>In a functional sense, the payments for technical assistance differ from the payments for licenses and rights. The former are payments for a new service -- the activities required to diffuse knowledge. Licenses and royalties, on the other hand, are economic rents; they are not payments for the production of any new goods or service. Thus, the "real" economic cost of transfer of technology is less than the nominal financial costs. Present institutional arrangements, however, give firms property or quasi-property rights in the ideas, data, and designs embodied in a finished system. Transfer requires payments to the owner of these rights.

The property rights firms have or should have in the ideas and concepts embodied in their designs is a much disputed issue in the U.S. aerospace industry. (See J. W. McKie, Property Rights and Competition in Procurement, The RAND Corporation, RM-5038-PR, June 1966.) In the Japanese co-production programs, corporate claims to proprietary data rights seem to have been generally recognized. Also, firms seem to have been generally willing to license products at fees that were relatively small parts of the total cost of the relevant item.

<sup>35</sup>This formulation and much of the discussion to follow is based on the work of Alchian and Hirshleifer. See A. Alchian, "Costs and Outputs," in M. Abromovitz, et al., The Allocation of Economic Resources: Essays in Honor of B. F. Haley, Stanford, Calif., 1959, pp. 23-40; J. Hirshleifer,

"The Firm's Cost Function: A successful Reconstruction?," The Journal of Business of the University of Chicago, Vol. 25, July 1962, pp. 235-255. See also W. Z. Hirsch, "Manufacturing Progress Function," Review of Economics and Statistics, Vol. 34, May 1952, pp. 143-155. These references present detailed formulations of the cost relationships discussed in this section.

<sup>36</sup>The Japanese produced 160 planes during the C-1 program, 30 during the C-2 program, and the equivalent of about 10 aircraft during the production of spare parts.

<sup>37</sup>The relationship between co-production and the costs associated with the rate of production depend on how the co-production program is organized. Recall the equation  $C = f(x, V, T, m)$ , and assume  $V$  is fixed. If  $T$  and  $m$  (the schedule) can be adjusted for the time required to transfer the program, or if no extra time is required to effect the transfer,  $x$  is not affected by co-production. If, however, transfer takes time and  $T$  and  $m$  are fixed,  $x$  will have to increase. If we make the usual assumptions about the relationship between  $C$  and  $x$ , there will be some additional indirect costs.

<sup>38</sup>Hirshleifer, pp. 239-240.

<sup>39</sup>Hirsch, pp. 35-36.

<sup>40</sup>Hirshleifer, p. 240.

<sup>41</sup>Harold Asher, Cost-Quantity Relationships in the Airframe Industry, The RAND Corporation, R-291, July 1956; L. E. Preston and E. C. Keachie, "Cost Functions and Progress Functions," American Economic Review, Vol. 65, March 1964, pp. 100-106, discusses the relationship between learning and economies of scale.

<sup>42</sup>"Slope" has a meaning in progress curve analysis different from its mathematical meaning. Here it refers to the ratio

$$\left( \frac{c_t}{c_{t/2}} \right) 100$$

where  $c_t$  is the production cost of the  $t^{\text{th}}$  unit of output.

<sup>43</sup>The crossing of the LAI and MHI progress curves is due, we believe, to labor's being for all practical purposes a fixed factor in a Japanese plant. Since workers cannot be discharged and there are relatively few aircraft programs at any one time, there is considerably less incentive in Japan to reduce the direct labor required during a program.

<sup>44</sup>Actually, 87 percent greater, were such computational accuracy warranted:  $[(6.9 - 3.7)/3.7] = 87$  percent. The estimate of Lockheed man-hours is understated for two reasons. First, it assumes a constant progress curve slope; the curve might have flattened out. More important, with each new model of the F-104 at Lockheed, the progress curve shifted upward. Undoubtedly, if the F-104J had been produced in the United States the man-hours for the first J version plane would have been higher than the end-point of Lockheed's F-104 progress curve shown for the earlier period.