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# Supersonic Transport Aircraft Hydraulic Systems

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**For future planning of the supersonic transport (SST) aircraft hydraulic systems, studies and analyzations have been made of the operation of present turbine-powered transport aircraft during the past 4 years. These studies have pinpointed areas that must be given extensive consideration in the design of new high-speed transport aircraft. Preliminary studies of the SST aircraft indicate that approximately 700 hydraulic hp may be used for various hydraulic systems. This might include 250 hp for the flight control system. It is anticipated that the hydraulic system operational temperatures will vary from 350° to 500°F. It is extremely pertinent that early studies be made of new systems of this type because of the large increase in functional power requirements and the severe environmental operational conditions.**

## Introduction

MAN has used fluid power for more than 2000 years to augment his own physical efforts. The earlier fluid power systems were water wheels and were used by the ancient Egyptians and Babylonians for milling grain and lifting water to higher levels for crop irrigation.

Modern power transmission by "oil hydraulics," however, did not come about until shortly after 1900 when a division of Vickers Inc. at Waterbury, Conn. produced the first workable power transmission. This transmission was later used in 1906 to train and elevate the guns on the battleship U. S. S. Virginia.

This short 60-year history of modern oil hydraulics coincides in development and scope with the 60-year history of man's ability to fly. In this time period man has seen the air vehicle speeds change from 38 mph to more than 25,000 mph, and a corresponding change in gross aircraft weight from 600 lb to approximately 500,000 lb.

The transition that started in 1958 from the piston engine aircraft to the turbine engine aircraft in the transport activity was as phenomenal as the past 4 years of space explorations. With the coming operation of the supersonic transport before the end of this decade, once again we will probably see a transition period that will be equally phenomenal.

With the careful preliminary formalized study initiated by the Federal Aviation Agency (FAA), together with NASA and the Air Force, in addition to those being carried out by the air frame and equipment manufacturers, the supersonic transport transition will be extremely progressive and effective.

A typical study of the preliminary configuration of this aircraft is shown in Fig. 1. However, prior to discussing the aspects of hydraulic systems in future supersonic transport aircraft, it might be well to see first what lessons have been learned from approximately the past 5 years of operation of the present turbine-powered transport aircraft.

### Present Commercial Jet Hydraulic System Studies

Operation of jet transports during the past 4 years has revealed areas in the hydraulic system operation which required additional study and modification to provide the optimum operation required.

In April of 1961, the Commercial Jet Hydraulic Systems Panel of the Society of Automotive Engineers was activated for the purpose of investigating and making recommendations for corrections on present jet hydraulic systems, and then applying this knowledge in the future design of Mach 3 transport systems.

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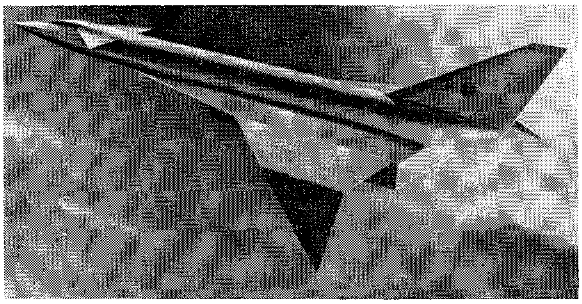

**Fig. 1 Proposed supersonic aircraft concept.**

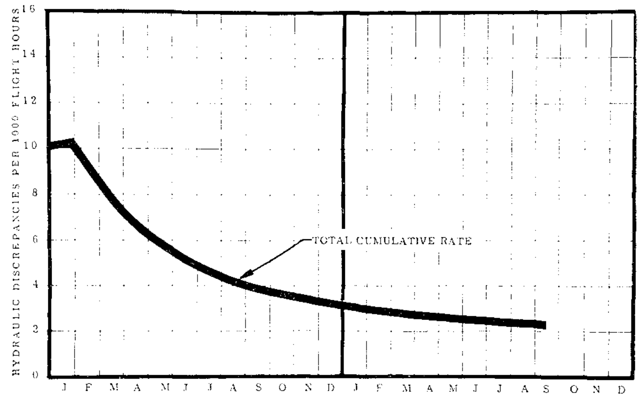


**Fig. 2 Total DC-8 hydraulic incidents.**

This panel is comprised of airframe, airline operator, and equipment representatives and divides its operation into three phases of activity. Simultaneous work is being done in all phases as follows:

***Phase 1 – Data collection***

During the past 2 years of this phase, data have been collected on all available hydraulic system malfunctions that have occurred during approximately the past 4 years. These data have been obtained from airframe manufacturers, airline operators, equipment suppliers, and the FAA. Not only have data been collected in regard to the aircraft during normal field operation, but data have been collected and reviewed covering initial airframe flight test programs.

***Phase 2 – Data analyzation***

The phase 2 area of activity includes the analyzation of malfunctions, their cause, and probable correction. In this study a number of charts showing rates of incidents or removals of hydraulic parts or components were made. Typical is that of the Douglas DC-8 aircraft operated by Delta Air Lines for the first 5 months of 1961, as shown in Table 1. As indicated in this table, the largest rate of incidents, that of 1.379/1000 hr, is in the leakage or failure of hydraulic lines. The second-and third-highest incident rates were "O" rings, seals, packings, and fittings, respectively. It may be noted that the engine-driven pump had a relatively low figure of 0.069 justified removals/1000 unit hr.

Total hydraulic discrepancies per 1000 flight hr for the total DC-8 aircraft fleet are shown in Fig. 2. This curve shows the material for all of 1960 and approximately the first 9 months of 1961. This shows a sharp reduction in discrepancies since the initial operation of this aircraft.

Additional typical data are those shown in Fig. 3. It shows the hydraulic system irregularities of Boeing 720 aircraft operated by United Air Lines for the first 6 months of 1961. As indicated in this material, seal, line, and hose irregularities are increasing at a rapid rate with the hydraulic pump, actuator, and valve incidents decreasing. The data shown in this figure show "raw" material. For example, Fig. 3 shows a pump irregularity rate of 0.65/1000 flying hr. Since there are two pumps per aircraft this would reduce the rate to 0.32 irregularities/1000 pump hr. Then, taking unjustified removals into consideration, this figure might further change to 0.16 removals/1000 pump hr.

Figure 4 shows the six highest items of incidents from one airline operation for the first 9 months of 1961. As indicated in this figure, seals have the highest incident rate.

Table 2 shows a summary of the major hydraulic incidents occurring on Delta Air Lines 880 and DC-8 aircraft through

**Table 1 Major hydraulic system incident data from Delta Air Lines on Douglas DC-8 aircraft, 1-1-61 to 5-30-61**

| Item | Hydraulic system incident component | Number of aircraft in operation | Number of aircraft flight hrs | Number of units per aircraft | Total unit hrs | Unscheduled unit removals or incidents | Unscheduled unit removals/1000 hr (not corrected for unjustified removals) | Number of known justified unit removals | Known justified unit removals/1000 unit hr |
|---|---|---|---|---|---|---|---|---|---|
| A | Hydraulic lines (steel/aluminum) | 6 | 7250 | ... | 7250 | 11 | 1.517 | 10 | 1.379 |
| B | "O" rings, seals, packings | 6 | 7250 | ... | 7250 | 6 | 0.828 | 5 | 0.690 |
| C | Fittings ("B" nuts, "T"s, etc.) | 6 | 7250 | ... | 7250 | 4 | 0.552 | 4 | 0.552 |
| D | Auxiliary motor pump | 6 | 7250 | 1 | 7250 | 2 | 0.276 | 2 | 0.276 |
| E | Landing gear valve | 6 | 7250 | 1 | 7250 | 2 | 0.276 | 2 | 0.276 |
| F | Rudder valve | 6 | 7250 | 1 | 7250 | 2 | 0.276 | 2 | 0.276 |
| G | Landing gear (general, brakes, tires, etc.) | 6 | 7250 | ... | 7250 | 1 | 0.138 | 1 | 0.138 |
| H | Pressure regulator valve | 6 | 7250 | 1 | 7250 | 1 | 0.138 | 1 | 0.138 |
| I | Horizontal surface trim motor | 6 | 7250 | 1 | 7250 | 1 | 0.138 | 1 | 0.138 |
| J | Filters (leakage, broken, etc.) | 6 | 7250 | 4 | 29,000 | 4 | 0.138 | 4 | 0.138 |
| K | Engine-driven pump | 6 | 7250 | 2 | 14,500 | 2 | 0.138 | 1 | 0.069 |
| L | Actuators | 6 | 7250 | 15 | 108,750 | 1 | 0.009 | 1 | 0.009 |
| M | Spoiler valves | 6 | 7250 | 1 | 7250 | 1 | 0.138 | 0 | ... |
| N | Brake valves | 6 | 7250 | 2 | 14,500 | 0 | ... | 0 | ... |
| O | System relief | 6 | 7250 | 3 | 21,750 | 0 | ... | .. | ... |

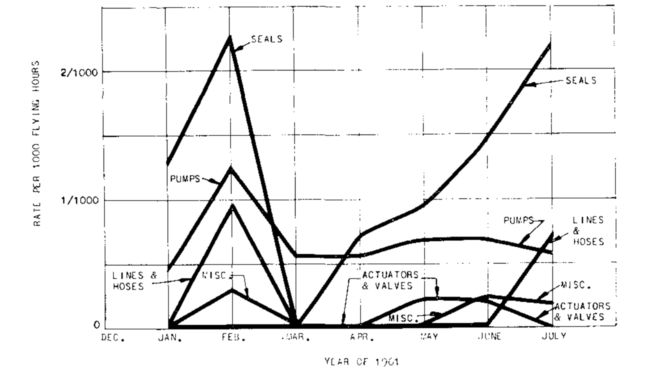


**Fig. 3 Boeing 720 aircraft hydraulic system irregularities.**

the early part of 1962. As indicated, the higher removal rates were in landing gears, seals, and fittings, with the lower removal rates being in filters and pumps.

***Phase 3—Documentation***

In this area the results of analyzation and studies of phases 1 and 2 are being documented for proper dissemination to the panel members and their representative organizations.

## Review of Present Data to Date

A review of the present commercial jet hydraulic system data to date has indicated that two-thirds of all hydraulic system incidents during the past 2 years have been due to external system leakage. This was largely in the areas of lines, fittings, hoses, and seals.

As a result of these studies, changes have been made to "O" ring specifications to provide higher temperature "O" rings. Changes have been made in the high-pressure hose to include a silicone sealant to eliminate the problem of moisture entering the covering of the hose and causing oxidation of the wire braid. Other areas have included replacement of many aluminum lines, fittings, and "B" nuts with those made of steel.

In the case of "O" rings, this panel is actively working with the Society of Automotive Engineers G-4 Committee in the preparation of a new specification covering ethylene propylene material for use with skydrol fluid.

Although many of the "O" ring manufacturers presently have prototype ethylene propylene material under development, the Douglas Aircraft Company has done very extensive developmental work on "O" rings of this type during the past three years. The results of these tests to date indicate that the ethylene propylene material shows exceptional heat resistance, extremely low compression set, low volume, a hardness change after soaking in Skydrol 500A fluid, high chewing resistance, and low leakage rates.

Figure 5 shows the volume-swell test as compared to present butyl compound materials. As indicated in this figure, the ethylene propylene material is well below the maximum

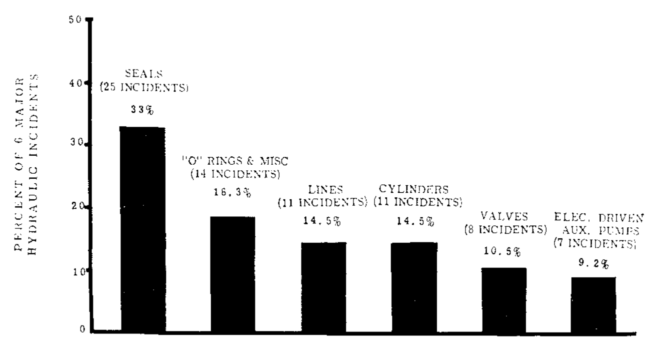


**Fig. 4 Major hydraulic incident areas.**

**Table 2 Summary chart Delta Air Lines major hydraulic incidents Convair 880 and DC-8 aircraft**

| Description of hydraulic components causing delay | Total incidents justified and unjustified: Convair 880 10-5-61 thru 1-27-62 (12 aircraft) | Douglas DC-8 11-22-60 thru 1-21-62 (6 aircraft) |
|---|---|---|
| Landing gear (actuators, cylinders) | 14 | 4 |
| Seals ("O" rings, etc.) | 7 | 9 |
| Fittings ("B" nuts, "T"s, etc.) | 6 | 4 |
| Brakes (actuators, cylinders) | 5 | 0 |
| Brake (valves) | 4 | 2 |
| Hydraulic lines (steel) | 3 | 6 |
| Hydraulic leakage (unknown origin) | 3 | 4 |
| Valves—general system (rudder, trim, stabilizer) | 3 | 0 |
| Filters (broken, leakage, etc.) | 1 | 2 |
| Pump, engine driven | 3 | 0 |
| Pump, auxiliary | 0 | 2 |

acceptable limit of 225°F, whereas the other six butyl materials fail in this respect.

After extensive Douglas laboratory tests, these seals are being service tested in present turbine-powered aircraft. It is believed that "O" rings of this type should be ready for industrial use within the next 6 months.

In addition to the hose changes, which include the silicone sealant previously mentioned, laboratory test programs are now being conducted with hoses having ethylene propylene rubber liners.

One factor that might be considered in the elimination of system leakage is the use of permanent jigs and fixtures for fabricating hydraulic system lines. With the extended use of the flareless-type fitting, this study has determined that the fitting is much less tolerant of line misalignment, and lines have to be made extremely accurate. A second factor in the reduction of system leakage might be the elimination of most short lines and numerous fittings, the minimizing of bulkhead fittings and hydraulic bosses. A third factor is an extremely effective, concentrated, and continuous quality-control effort in relation to lines and fittings.

The continuous quality-control phase previously mentioned cannot be overemphasized. At the present time there are more than 70 manufacturers of aircraft fittings in the United States. It has been determined that in some cases, after an aircraft has been put into operation, various purchasing activities may change suppliers of fittings several times. If a change is made, it is absolutely necessary that effective quality control re-evaluations be made and then continued.

Figure 6 shows a summary for 1961 and the first 7 months of 1962 of the Convair 880 aircraft in operation with Delta Air Lines. This figure shows the main hydraulic system discrepancies as a percentage of total mechanical delays and as a percentage of actual total departures for all reasons. As indicated in June of 1962, the main hydraulic system accounted for $\frac{1}{10}$ of 1% for all delay reasons.

A similar chart for the landing gear system of this aircraft covering the same period is shown in Fig. 7. Figure 8 shows similar data for the DC-8 main hydraulic system irregularities with Delta Air Lines for the same period of time. As indicated in this figure, the hydraulic system accounted for approximately $\frac{1}{2}$ of 1% of the total departure delays. Similar data for the DC-8 landing gear system are shown in Fig. 9.

Figure 10 shows a summary through June 1962 of the hydraulic irregularities of the DC-8 aircraft with United Air Lines. As indicated, there has been a general reduction of total irregularities since the peak in June of 1961. This reduction can be attributed to a number of items, such as

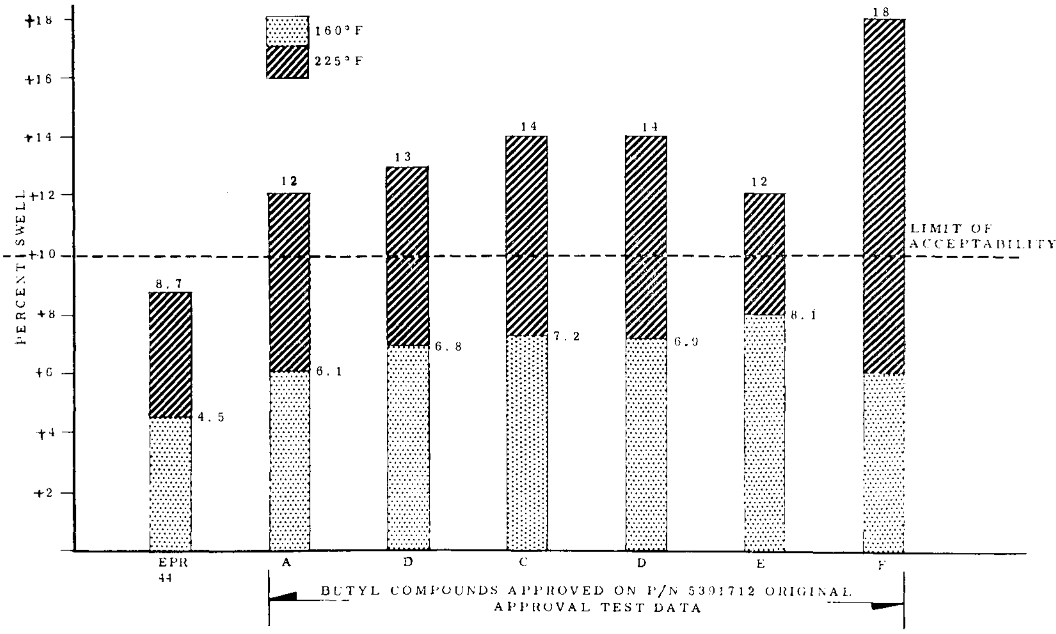


**Fig. 5 "O" ring volume swell data.**

improved field maintenance, changes in the system configuration, and so forth.

Figure 11 shows the total system irregularities for the same period of time for the Boeing 720 Aircraft. As indicated in this figure, there have been a number of peak irregularity areas with a general decline.

### System Filtration

Studies by the Commercial Jet Hydraulic Systems Panel during the past 2 years have indicated that very great benefits result from added system filtration. This has been both in respect to over-all system reliability as well as general efficiency of system operation. In present commercial jet aircraft a number of filters have been added in the pump case drain and return system lines.

At the present time Boeing is field service testing in six 720 aircraft a large duel element filter in which the first stage has a $\frac{1}{2}$-$\mu$ nominal rating and the second-stage element has a $1\frac{1}{2}$-$\mu$ nominal rating. It is anticipated that filters of this type would prove very beneficial in this operation.

The first-stage element is an inexpensive paper-type configuration, whereas the second-stage element is a stainless steel woven wire type. In future operation, periodic monitoring of various system cleanliness conditions would prove very beneficial.

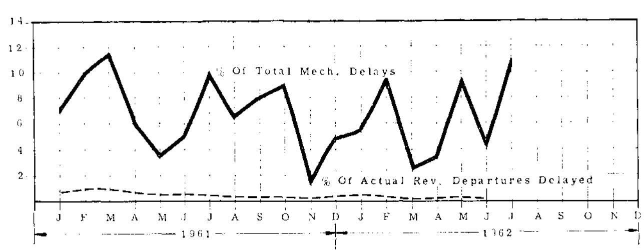


**Fig. 6 Delta Air Lines Convair 880 hydraulic system data.**

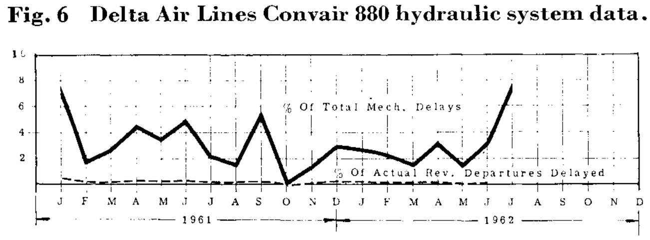


**Fig. 7 Delta Air Lines Convair 880 landing gear system data.**

### Supersonic Transport Hydraulic Systems

The study of the past 4 years of turbine-powered transport hydraulic systems will permit a much clearer picture for the initial development of supersonic transport fluid power systems. This will permit greater optimization of this future transport's fluid-power system, which is believed to be a shorter time period than occurred on the present turbine-powered aircraft.

Although the United States has been engaged in supersonic flight for the past 15 years, the total amount of accumulated supersonic flight time is actually very small. This is particularly true when it is compared with the total monthly flight time of U. S. commercial aircraft carriers. There is approximately 380,000 hr per month flown on commercial aircraft whereas the total hours for the past 15 years of supersonic flight time, including both military and research, is only approximately 40,000 hr, or equal to $3\frac{1}{2}$ days of normal commercial flight time.

This comparison shows that there are many new areas to be investigated, and careful consideration must be given to all functions of a supersonic transport. In addition to the study of the past commercial turbine-powered aircraft, a study of the present B-58 and B-70 fluid-power systems will also prove extremely beneficial.

The general characteristics of the Mach 3 aircraft are summarized in Table 3. As indicated in this table, this aircraft will probably accommodate 100 to 150 passengers, have a takeoff weight of 400,000 lb, and have a range of approximately 3500 naut miles. Because of aerodynamic conditions,

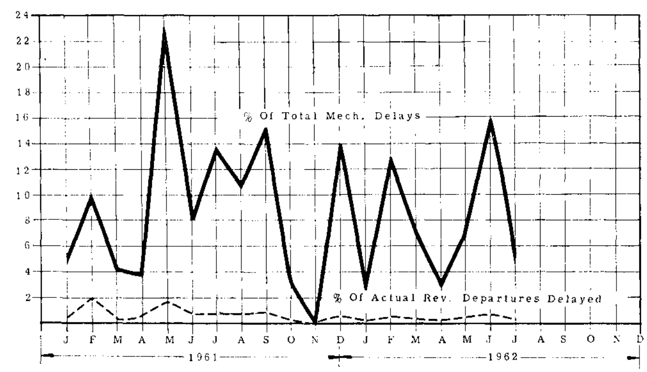


**Fig. 8 Delta Air Lines DC-8 aircraft hydraulic system data.**

its fuselage will have a small frontal area and will be approximately 200 ft long with a wing span of approximately 100 ft. It is estimated that its cruising altitude will be 60,000 to 80,000 ft.

Because of the general operating characteristics of this aircraft, the hydraulic flight controls are far more critical than any commercial aircraft previously conceived. Not only must the aircraft have excellent flight-control characteristics at subsonic speeds where it will spend more than one-half of its flight time during ascent and descent, but it must have extremely high-responsive controls at the supersonic conditions. In addition, it must be controllable and have excellent stability, with a suitable pilot-feel characteristic through the transonic range. The estimated skin temperatures of this aircraft may range from 600°F on the nose to 400° to 500°F cabin skin temperature. Some areas in the engine section may also be in the 400° to 800°F range.

Less than a decade ago engineers were concerned with how to cope with structural temperatures of 300° to 400°F in the selection of materials. Now they are concerned with commercial passenger-carrying aircraft that will have double these temperatures. This, of course, will require extensive use of stainless steels and titanium. This will probably result in hydraulic system fluid temperatures of 350° to 500°F with ambient temperatures up to 600°F. This is quite an increase

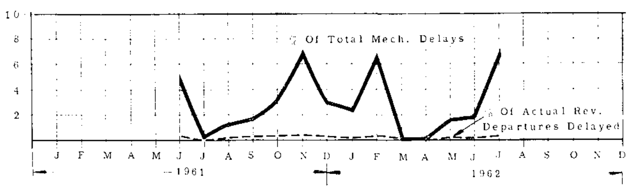


**Fig. 9 Delta Air Lines DC-8 landing gear system data.**

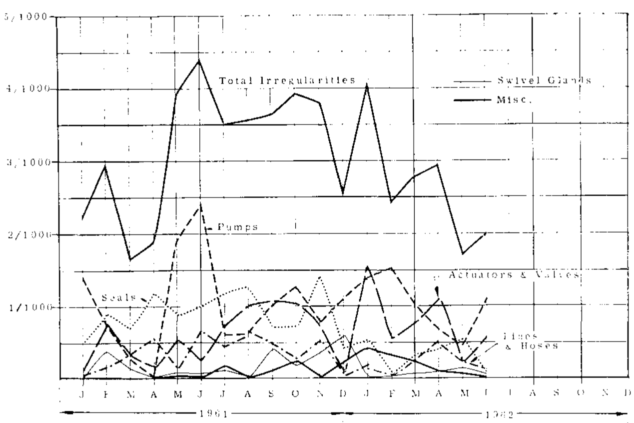


**Fig. 10 United Air Lines DC-8 hydraulic system incidents.**

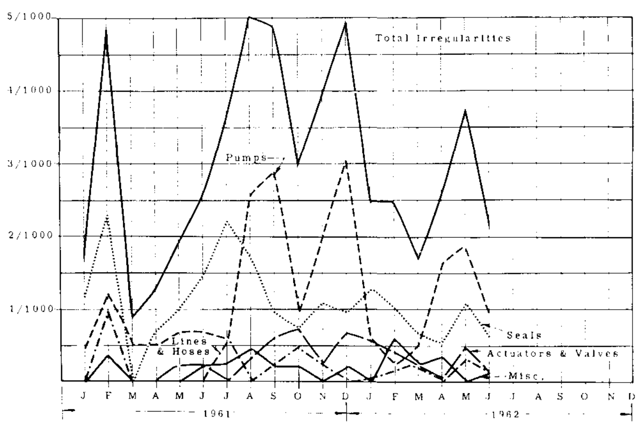


**Fig. 11 United Air Lines 720 hydraulic system data.**

**Table 3 Proposed supersonic transport characteristics**

| | |
|---|---|
| Cruising speed | Mach 3 |
| Cruising altitude | 60,000–80,000 ft |
| Passengers | 100–150 |
| Gross weight | 400,000 lb |
| Range | 3500 naut miles |
| Estimated wing span | 100 ft |
| Estimated fuselage length | 200 ft |

from our present subsonic jet transport hydraulic systems that are less than 200°F.

### System Functions

There probably will be many more hydraulic functions on the supersonic transport than in today's present commercial jet aircraft. The present Douglas DC-8 aircraft has 86 hydraulic hp available, whereas the Convair 880 aircraft has approximately 170.

It is interesting to note that the B-70 aircraft, which will be a stepping stone to a Mach 3 commercial aircraft, has a hydraulic system capable of 2500 hp. This aircraft may use peak horsepower for landing gear systems of 510, and perhaps a peak horsepower in the primary flight control system of 980.

A preliminary study indicates that in the supersonic transport the hydraulic power will be supplied by 4–8 engine-driven pumps and will provide a total hydraulic horsepower of 500 to 1000. Typical operations for a hydraulic system of this type are shown in Table 4.

Figure 12 shows the estimations of hydraulic horsepower requirements for supersonic transports by five airframes that are presently making studies. As can be seen from this figure, these estimates vary from 400 to 2000, whereas the B-70 aircraft has a hydraulic horsepower capability of 2500. It is believed that the difference between the military and civilian requirements will result in a far lower figure for the civilian aircraft. It is therefore anticipated that approximately 700 hp might be a more likely estimated figure. If this were the case, this might be divided into system requirements as shown in Fig. 13.

As indicated in this chart, the primary flight-control system might have a maximum value of 250 hp. It is anticipated that 25 continuous hp will be required for quiescent leakage of servo valves, and the normal flight-control operation might be in the neighborhood of 100 hp.

Although in the environmental system the cabin pressurization requirement may not be significantly greater than on present supersonic aircraft, the ram air temperature will be approximately 650°F. This will then require an extensive cooling requirement of approximately 100 lb of air/min using a two-stage cooling system. This is estimated to have a requirement of approximately 200 hp.

Figure 14 shows a possible layout of the supersonic transport and indicates locations of basic auxiliary hydraulic power requirements including flight controls, environmental controls, fuel handling systems, and accessory drive systems. As outlined in Fig. 13, the hydraulic power requirements for the propulsion system will include fuel-transfer and fuel-boost

**Table 4 Typical operations for a hydraulic system of 500 to 100 hp**

| | |
|---|---|
| Flight controls | Fuel jettison pump drive |
| Wing flap drive | Brake system |
| Landing gear operation | Windshield wipers |
| Spoiler operation | Hydraulic driven fuel pumps |
| Leading edge flaps | Hydraulic driven fuel transfer pumps |
| Air compressor drive | Hydraulic driven fuel boost pumps |
| Nose wheel steering | Hydraulic driven alternator drives |
| Engine controls | Hydraulic driven engine starting system |
| Engine thrust reverser operation | Wing variable geometry system |

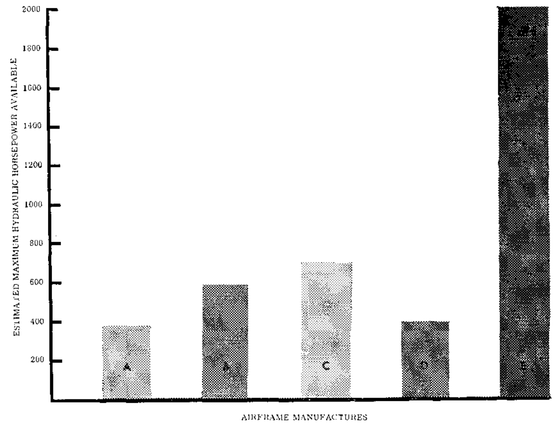


**Fig. 12 SST hydraulic power requirement estimates.**

pumps for each of the four engines. The transfer pumps will be required to move the fuel at scheduled rates from a number of fuel seals to the main fuel pump tanks. The fuel-transfer function will be extremely complicated in this type of aircraft because of the large amount of fuel required and the fact that much of it must be distributed remotely from the center of gravity of the aircraft.

### Mainpower Pumps and Hydraulic Starting

Present studies are being made on both 3000 and 4000 psi pressure systems for the supersonic transport air-craft. The latter system, of course, would provide greater horsepower per pound, and as previously indicated would probably operate in a 350° to 500°F fluid temperature range.

Pumps and motors of this type have been under development for the past several years, and the equipment finalized for the B-70 application should provide a ready-made steppingstone. One of the main system pumps developed for the B-70 aircraft has a 5.0 cu in. displacement, operates at 5000 rpm, 4000 psi pressure, and will develop approximately 250 hp. This same unit will be used as a hydraulic motor for hydraulic engine starting before reverting to its normal pumping function.

It is believed that hydraulic starting in an aircraft of this type will be extremely pertinent, as this will save both the weight and space of the conventional-type starter. A further advantage is that with essentially no weight penalty, engine starting can be initiated on more than one particular engine of the four powering this aircraft. Hydraulic engine starting has been accomplished in various test and field applications

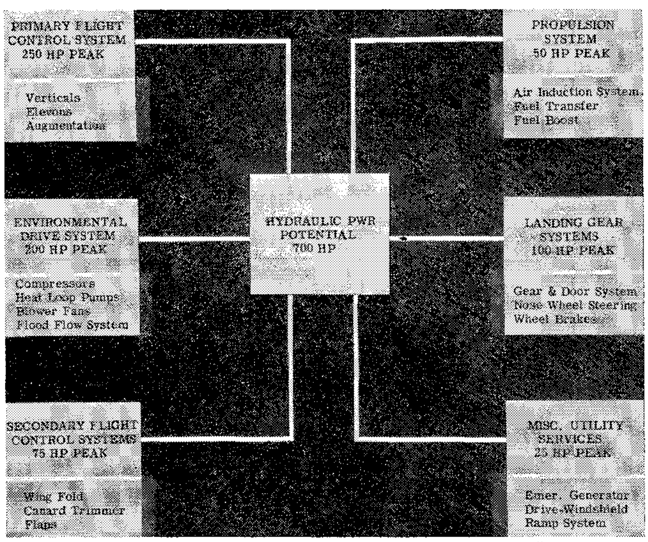


**Fig. 13 Estimated breakdowns of SST hydraulic power requirements.**

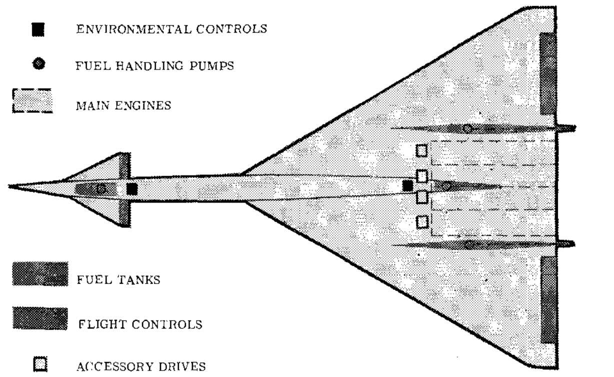


**Fig. 14 Hydraulic power locations in SST.**

since 1947 and has been used satisfactorily in field trials on such aircraft as the Lockheed Electra, F-100, and F-3D aircraft.

Because of the temperatures involved, stainless steel and tool steels would be used extensively throughout a pump of this type. This would include the use of these materials for cylinder block as well as the drive shaft bearings. To minimize any external leakage, stainless steel metallic seals would be used in place of elastomeric "O" rings. The shaft seal would use a carbon sealing face, which would also permit higher-pressure case operation.

It is anticipated that there would be many more hydraulic functions on the Mach 3 aircraft than are presently used on subsonic transports. As previously outlined, all of the fuel system pumps might be hydraulically driven. In all probability these pumps might be submerged in the fuel reservoir, and because of their surrounding conditions it is far easier to have them hydraulic motor driven than electric motor driven.

Although there are 36 hydraulic motors used in the B-70 aircraft for various system operations, it is believed that this high-speed transport might use 15 to 20 motors in its system. For system simplification and weight saving, it is anticipated that the motors might be internally drained, eliminating a case drain line. This would then result in the motors operating with higher-case pressures, possibly up to 500 psi.

For accomplishing specific purposes these various motors would have auxiliary control equipment directly connected to them, such as directional control valves operated by solenoid pilot valves, speed limiting controls, relief valves, etc.

## Fluid and Temperature Investigations

As previously outlined, hydraulic system fluid temperatures of 350° to 500°F will be felt in this system. It appears that the fluid most suitable for this operation would be the super-refined petroleum base fluid of the MLO-7277 type. This fluid, which has a naphthenic base, is summarized in Table 5. As indicated in this table, this fluid has a flash point of 420°F and an auto-ignition temperature of 735°F. Although it shows a pour point of −35°F, the viscosity properties of this fluid indicate that for normal system operation, 0° to −10°F might be the lower operational limit.

For providing heat to certain static hydraulic system areas during high-altitude low-temperature flights, and also under

**Table 5 MLO fluid characteristics**

| | |
|---|---|
| Viscosity, centistokes | |
| 20°F | 2812 |
| 100°F | 72.8 |
| 210°F | 7.7 |
| 400°F | 1.6 |
| Flash point, °F | 420 |
| Auto ignition temperature, °F | 735 |
| Pour point, °F | −35 |

other conditions for providing a system circuit flow and keeping "hot spots" from occurring, it is anticipated that the hydraulic system would probably use a series of bleeds. That is, high-pressure fluid is diverted to the low-pressure side to produce system circulation.

Usually $\frac{1}{4}$ to $\frac{1}{2}$ gpm flows are sufficient to accomplish the desired system temperature stabilizations. These system bleeds are now being used in certain present subsonic turbine-powered aircraft.

Although some present high-temperature systems are using the MLO-8200 series of fluids, it is felt that these disiloxane based fluids have lower lubricity values than the petroleum based fluids.

More than 4000 hr of operation have been conducted in laboratory tests with the MLO-7277 fluid in the 550°F range. Of this time, more than 250 hr were conducted on one test pump. The fluid used for this high-speed transport will be required to have thermal stability, inasmuch as there may be as many as four thermal cycles, or four Mach 3 flights/24-hr period. Care must be given to eliminate both air and water from the system to provide the correct system response and eliminate any possibility of "spongy" system operation.

## System Filtration

Studies of the Commercial Jet Hydraulic Systems Panel during the past 2 years have indicated very great benefit from added system filtration. This has been both in respect to over-all system reliability as well as general efficiency of system operation. In present commercial jet aircraft, a number of filters have been added to the pump case drain and return system lines.

Studies have also indicated that certain advantages are gained from relying on the airborne system filters for cleaning up system with no outside flushing. During the past few years considerable difficulty has been experienced with trying to clean up certain systems by using ground carts for flushing purposes. At times more contaminant is put into the system than removed from the system.

## Tubing and Fittings

It is anticipated that most of the tubing and fitting material will be of a stainless steel high-strength alloy. As in the case of both the Lockheed Electra investigational programs and the present B-70 design, it is anticipated that tubing connections will be minimized with connections made through manifolds. This is largely because of a reliability aspect in reducing the leakage areas, but also results in considerable saving to the aircraft weight, possibly as much as several thousand pounds.

## Conclusion

The results of the past studies on commercial jet hydraulic systems have proved extremely beneficial in the nature of optimizing hydraulic system operations. With this continued monitoring and study with additional specialized studies in specific areas, prior to the end of this decade supersonic commercial jet transport will probably be seen playing a major effort in airline transportation industry.

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# Analytical Method for Designing Turbine Nozzle Partitions

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**An analytical method of determining the blade shape of turbine nozzle partitions and stationary blades for subsonic flow is presented in this work. Two important advantages over the present design methods are noted, namely: The initial design and the iterations to the desired blade shape can be done by a computing machine, and the profile of the suction and pressure surfaces can be described by a continuous curve from the leading edge tangent point to the trailing edge.**

## Nomenclature‡

$\theta_E$ = inlet angle
$\theta_X$ = exit angle
$\theta_1$ = suction surface exit angle
$\theta_3$ = suction surface inlet angle
$\theta_4$ = pressure surface exit angle
$\theta_5$ = pressure surface inlet angle
$\theta_2$ = angle of slope at throat
$\theta_{te}$ = trailing edge wedge angle, 6.5°
$\theta_{le}$ = leading edge wedge angle, 31.0°
$\theta_6$ = $\theta_3$
$\theta_7$ = $\theta_5$
$TET$ = trailing edge thickness
$XER$ = leading edge radius
$DT$ = nozzle throat width
$W$ = blade width
$H$ = blade height
$P$ = blade pitch
$L$ = $W - XER$

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‡ Definition of symbols for Fig. 2.

## Introduction

ONE of the present methods of designing turbine nozzle partitions is to lay out the blade shape, based on cycle data and structural requirements, and then analyze the flow field to determine the velocity and pressure profiles