BK 117 A NEW HELICOPTER OF INTERNATIONAL COOPERATION

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KAWASAKI HEAVY INDUSTRIES
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FIFTH EUROPEAN ROTORCRAFT AND POWERED LIFT AIRCRAFT FORUM
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1. Abstract

Kawasaki Heavy Industries, Aircraft Group (KHI) and Messerschmitt-Bölkow-Blohm GmbH, Helicopter Division (MBB) were independently performing conceptual layout studies for a light twin engine helicopter within the 8 to 10 seat class since the early 1970ies.

In 1975 both companies decided to combine their efforts after comparing their layouts, exchanging their objectives and basic ideas. Following this, an integrated team from MBB- and KHI-engineers was formed to work out a preliminary design for a helicopter to be jointly developed by the two companies.

The BK 117 helicopter, which was defined during this efforts, is currently under development by MBB and KHI.

The BK 117 is characterized as a twin engine multipurpose helicopter equipped with AVCO-Lycoming LTS101 turboshaft engines. The four-bladed rotor (11 m diameter) is a rigid type, similar to the BO 105 design. The maximum take off weight is 2800 kg. The cruise speed of 265 km/h represents the technical progress of the 1980ies.

During the design of the helicopter, special attention was paid to achieve a high degree of commonality to the BO 105 which can be called the parent helicopter of the BK 117. The aircraft was designed for certification in accordance with FAR Part 29, Cat. A as well as for the British CAA requirements BCAR. The development, including ground and flight testing, is shared 50 : 50 between both companies.

Two prototypes are currently undergoing flight testing; one at MBB in Germany and one at KHI in Japan.

2. Historical Background

After the successful introduction of the BO 105 helicopter into world wide operation, there was a strong determination at MBB to expand the activities by adding a new model in order to achieve a helicopter family step by step. For this conceptual layout studies as well as market analysis had been performed since the early 1970ies. The concept studies were based on the rigid-rotor technology and concentrated on twin-engine installations. It was found that a helicopter in the 8 to 10 seat class was the one with the best market chances apart from the 5 to 6 seater size. In addition to the know how, which was gained from the BO 105 program and from research efforts, MBB was able to accumulate experience in helicopter production during license production of the UH-1D and CH53 helicopters, wherein MBB had a remarkable production share.

KHI was producing helicopters under license contracts from Bell Helicopter Company, Boeing Vertol and Hughes since many years. Additional research efforts have been made in the areas of helicopter technology. KHI was also flight testing a rigid-rotor concept for several years. This company also intended to enter the helicopter market with a product of it's own design.

During technical discussions between the companies on these subjects, which first included Boeing Vertol, it was found the baisic ideas of the companies being very close. As a result it was decided to combine the resources and efforts in a joint development program. An integrated team was arranged at the MBB plant in Ottobrunn in early 1976. About twenty engineers were involved in this activity being a joint 50:50 effort from MBB and KHI. At that time Boeing Vertol had already decided not to participate in this program because of their workload in other projects, whereby the required manpower was not available.

The first action in the preliminary design phase was to define jointly the design requirements and objectives as follows:

- High degree of versatility for the missions: light transport, offshore, rescue, ambulance, external load operation and executive transport, possiblity for a quick change from one mission to another.
- Certification according to FAR Part 29, Cat. A by LBA (german airworthiness authority); and CAA-BCAR
- Design for single pilot IFR-Certification
- Take-off weight approx. 2800 kg
- Range with normal fuel . . . . . . approx. 550 km
  Range with auxiliary fuel . . . . . approx. 800 km
- Cruise speed . . . . $\geq$ 260 km/h
- Operating range OAT from: . . . . . $-45^{o}C$ to $+50^{o}C$
- Rotor starting and shutdown at wind velocities up to 85 km/h from every side
- Cabin size for 1 pilot and 7 passengers in standard configuration alternatively 1 pilot and 9 passengers in a high density seat arrangement;
- Large rear loading doors and cargo compartment combined with cabin; similar to BO 105;

- Commonality with BO 105 components wherever reasonable
- Initial TBO and Retirement Life at least as high as for BO 105 in 1976.

Based on these objectives, preliminary design studies were carried out. A wide variety of configurations was evaluated which covered completely new designs as well as uprated BO 105-versions. As the result, the BK 117 configuration was selected. The preliminary design phase was finished in May 1976 with the general specification of the helicopter as well as the detail specifications for all major subsystems and components worked out and approved by both companies.

Marketing studies were also an important part of the preliminary design effort.

In parallel to the engineering activities, negotiations on the other related areas were initiated, which were concluded with signatures of basic agreements for:

- Development share; which was decided to be valued of 50 : 50
- Production share; an agreement was made for 50 : 50 production for parts and subassemblies. Final assembly at each company.
- Market share
- Cost estimation and expected sales price
- Recoupment of development cost
- Major schedule plan for development and production

After finalizing the contracts the BK 117 development was started in late 1976.

3. BK 117 Technical Definition and Description

During the definition of the final configuration, special attention was directed to obtain an optimum combination of styling and mission specific requirements, which means that the requirements for low weight, aerodynamic shape for low drag, accessibility of all assembly groups and subsystems for maintenance as well as mission versatility had to be balanced carefully. A low empty weight for the structure was obtained with the BK 117 configuration offering a large volume for useful load in combination with a minimum wetted surface. This resulted in a shape very similar to the BO 105. In order to achieve the goal for the cruise speed, special effort was spent to reduce the aerodynamic drag. The shape of the aircraft was optimized during a wind tunnel test program in the KHI-owned wind tunnel at Gifu. At this time also maintenance questions were solved using a full scale mockup.

3.1 Main Data and Characteristics (see fig. 1)

- Main Rotor

. 4-bladed, rigid type (BO 105 system)	
. Rotor diameter	11 m
. Blade chord (rectangular planform)	0,31 m
. Solidity	7,18 %
. Airfoil NACA 23012-23010 modif. (blade-tip)	
. Blade tip speed	220 m/s
. Main rotor RPM	383 U/min

- Tail Rotor

. 2-bladed, semi-rigid	
. Rotor-diameter	1,9o m
. Blade chord (rectangular planform)	0,18 m
. Solidity	12 %
. Airfoil MBB-S102E	
. Blade tip speed	217 m/s
. Tail rotor RPM	2169 U/min

- Main Dimensions

. Overall length	13 m
. Overall height (tail rotor horizontal)	3,25 m
. Tail rotor ground clearance	1,93 m
. Length of fuselage	9,5o m
. Width of fuselage	1,55 m
. Passenger cabin	
Width	1,47 m
Length	2,02 m
Height	1,29 - 1,24 m
. Cargo Compartment	
Width	1,23 m
Length	1,10 m
Height	1,24 - 1,02 m
. Total volume cabin + cargo compartment	5,17 m^3

- Weights

. Max. take-off weight	2800 kg
. Empty weight (standard)	1410 kg

- Performance

. Max. speed (SL) V_{NE}	275 km/h (149 kts)
. Cruise speed	264 km/h (143 kts)
. Range (normal fuel) ISA SL	545 km
. Range (auxiliary fuel) ISA SL	910 km
. Rate of climb	10 m/s (1970 ft/min)
. Ceiling HOGE, ISA	3150 m (10340 ft)
. Single Engine Service Ceiling (150 ft/min R.O.C.)	3000 m (9840 ft)

3.2 Rotorsystem (see fig. 2)

The rotorsystem is similar to that of the BO 105. A four-bladed system was selected using a shift hub and flexible composite blades tailored in mass and stiffness for the required equivalent flapping hinge offset, which is about 14% in relation to the rotor radius. The dynamic tuning is also similar to that of the BO 105.

The rotor blades are all-fiberglass (see fig.3) of similar design to the BO 105 blades. A C-spar in the leading edge area is built up from unidirectional E-glass rovings with each tape running from the blade tip to the root, there forming a loop and running back to the blade tip. The spar carries the loads coming from the centrifugal force, and flapwise bending as well as partially torsion and edgewise bending. The skin is made from E-glass fabric with a fiber orientation of $\pm 45^{\circ}$ related to the blade axis. In order to stabilize the blade structure in the trailing edge area, a foam core (polyvinyl-chloride) is bonded into the blade, filling the blade interior completely. The loads are transfered from the blade to the rotor hub by a two piece titanium fitting which encloses the blade root and loop. There is no bonding between fitting and blade structure. The blade chordwise c.g. location is achieved by a lead balance mass being installed at the leading edge. To avoid erosion a single piece of stainless steel erosion protection strip is bonded to the blade leading edge. The blade is massbalanced by adding trim masses to the blade tip by means of a tube which is installed at the blade tip.

As far as geometry is concerned, a rectangular planform was selected. From the inner blade end to 80% radius the blade has a constant thickness ratio of 12%. A modified NACA 23012 airfoil section identical to the BO 105 blade is used in this area. From 80% radius to the tip, the blade is linearly tapered to a modified 23010 airfoil section at the blade tip. A linear twist of 10° is built into the blade. The manufacturing process as well as the materials except erosion protection are identical to the procedure used for BO 105 blades. The blade design allows the integration of deicing blankets without changing the blade structure.

The rotorhead (see fig. 4) which is machined from forged titanium includes hub, inner sleeves, Bendix tie bars for centrifugal force retention, roller bearings to transfer share loads and pitch arms. The bearings are lubricated through a central oil reservoir, which is installed on top of the rotorhead. The oil level can be checked easily during the preflight inspection, because the transparent reservoir is visible from the ground. Therefore no maintenance for the rotor is required. The rotorhub is mounted to the flange of the rotormast by 12 preloaded necked-down bolts. The torque loads are transfered from limb to shaft via shear bushings.

The hub assembly is a common part of BO 105 and BK 117, thus being interchangeable.

3.3 Transmission System

The complete drive system is arranged on a deck on top of the cabin. Fig. 5 indicates schematically how the dynamic system - including rotor, upper controls, main transmission, engines and hydraulic boost - is installed. The main gearbox has only two stages; (see fig. 6). The first stage (one for each engine) is a bevel gear stage with a high reduction ratio. Oil lubricated sprag type over-running clutches are installed at the input drives of the main gearbox. The second stage, which is the combining stage, is a spurgear type. The output spur gear is splined to the rotorshaft separately supported by two bearings on the upper and lover end of the gearbox case. The tail rotor is driven by a combination of a spur gear and a bevel gear stage. The rotorbrake is integrated into the tail-rotor drive flange at the output from the main gearbox. The gearbox also incorporates two separated independent auxiliary drive systems for hydraulic pumps, oil pumps and oil cooling fans. There are two independent lubrication systems. All oil tubes are installed inside the gearbox case, thus avoiding oil loss due to a failure of an oil tube. The two oil cooler moduls which also include the engine oil cooling element are located on both sides of the gearbox. The coolers are directly attached to the gearbox structure (see fig. 7). The rotorloads are transfered from the gearbox by an arrangement of four vertical struts - carrying vertical forces, pitching and rolling moments -, two longitudinal struts - carrying longitudinal forces and torque - and a single lateral strut - carrying lateral forces. The installation is designed for optional installation of a vibration isolation system being currently under development. The tail rotor is driven by a long shaft and intermediate tail-rotor gearbox of a design similar to that of the BO 105. All misalignment couplings of the drive system are of flexible type and therefore free of maintenance.

The helicopter is powered by two Avco-Lycoming LTS101-650B-1 turboshaft engines with the following ratings

-	2 1/1 min. power (OEI)	485 kW	(650 shp)
-	Take-off power (5 min)	448 kW	(600 shp)
-	Max. continuous power	410 kW	(550 shp)
-	SFC at take-off power rating	$0{,}348 \frac{kg}{kWh}$	$(0{,}572 \frac{lb}{shp\ h})$
-	SFC at max. continuous	$0{,}354 \frac{kg}{kWh}$	$(0{,}582 \frac{lb}{shp\ h})$

The output speed is 6000 rpm; (see fig. 8)

In order to ensure the full safety of the twin turbine installation according to FAR Part 29 Cat. A, fuel-, oil-systems and all other related subsystems are duplicated, independent and isolated. The fuel cells of the bladder type are installed below the cargo compartment with their C.G. close to the C.G. of the helicopter.

3.4 Flight Control System

The mechanical controls for main- and tail-rotor are exclusively using push pull rods. The cyclic controls are equipped with a spring feet system using the hardware from the BO 105. The main-rotor controls include a duplicated hydraulic boost system (see fig. 9). The system is integrated into one modularized single package. There are no lines or hoses attached to the fuselage. The whole unit can be installed as a single assembly, thus significantly reducing maintenance requirements. The boost system uses existing BO 105 parts. It is installed on the transmission deck in front of the main transmission and attached by four bolts to the fuselage mounts; (see fig. 5). The upper control system (mixing linkage, swashplate assembly, pitch links) is identical with that of the BO 105 and therefore fully interchangeable between both helicopters.

3.5 Fuselage Structure (see fig. 10)

Generally the fuselage is a riveted aliminium semi-monocoque design. In order to keep manufacturing cost as low as possible, the metal structure is only single curved. Extensive use was made of KEVLAR material also for structural elements. For the forward and aft sections of the fuselage, which are compound curved, a KEVLAR/EPOXY-sandwich design with nonmetallic honeycomb core is used. In addition, all cowling doors are made of KEVLAR. Approx. 40% of the surface area is of KEVLAR-material. The cabin floor which has the same level as cargo and passenger compartment is made of aluminium sandwich, as well as the structure enclosing the fuel tanks. The tailboom is similar to that of the BO 105. The structure is identical to the BO 105 antitank helicopter version.

The horizontal stabilizer with a span of 2,5 m and the large, cambered endplates are completely made of KEVLAR. Fig. 11 shows the assembly. A cross section of the horizontal stablizer is given in fig.12, which shows the sandwich skins and the filament wound spar/shear web arrangement.

3.6 Tail Rotor

The tail rotor is of the two bladed teetering semirigid type - see fig. 13. The tail-rotor hub is identical with the latest version of the BO 105 tail-rotor hub. It has a built-in delta three flapping hinge of 45^{o}. All bearings are teflon fabric bearings.

The tail-rotor blade is of a new design which uses a MBB-developed advanced cambered airfoil with a thickness ratio of 8%. This airfoil ensures a much higher tail-rotor thrust capability than the standard No. 0012. It is manufactured of E-glass-epoxy, using a similar design to that of the main rotor blade. Some important structural improvements were made in order to increase the impact resistance of the blade. As demonstrated this blade is able to cut a 60 mm diameter wooden dowel without loosing its integrety or thrust capability.

3.7 Undercarriage

Several arrangements had been studied and discussed with operators. As a result a skid type landing gear of similar design to that of the BO 105 was selected for the standard version.

3.8 Electrical System

The electrical system which is basically a 28V DC includes two engine mounted starter generators and a 28 Ah battery. AC is provided by static inverters. During the design of the electrical system the requirements for IFR were already considered.

3.9 Equipment and Interior

Special efforts have been directed to obtain a specious, unobstructed passenger/cargo compartment, which is schematically shown in fig. 15. Due to the fact that there is one single unobstructed space of almost equal height, numerous variations of seat arrangements are easily possible. Especially for ambulance/rescue operations, there is enough space for pilot, physican, medical attendant, medical equipment and two litters side by side which can be arranged in a level or a tiltered position.

The cabin/cargo room is easily accessable from each side through large sliding doors or the rear clamshell doors as shown in fig. 17 and fig. 18.

In order to adapt the helicopter to the different operational requirements, mission equipment packages such as rescue hoist, emergeny flotation gear, cargo hook, loudspeakers, auxiliary fuel tanks etc. are currently under development. To a large extent the special equipment kits will be identical to those of the BO 105.

4. Basic Performance Characteristics

Fig. 19 and fig. 20 show performance curves demonstrationg that the high ratio of installed power to gross weight results in very attractive performance during normal flight (with both engines operation) and during single engine flight. A payload versus range diagram is given in fig. 21.

5. Major Program Milestones

- Beginning of preliminary design phase by an integrated MBB-KHI Team	Nov. 75
- Development go-ahead	Febr. 77
- Rotor test bench (whirl tower) completed for test runs at MBB	Nov. 78
- Prototype P1 (ground test vehicle) beginning of tie-down tests at KHI	March 79
- First flight of prototype P2 at MBB in Ottobrunn	13. June 79
- First flight of prototype P3 at KHI in Gifu	11. Aug. 79
- First flight of first preproduction helicopter S01 at MBB	July 1980
- LBA and JCAB certification	End 1980
- First deliveries	End 1981
- FAA / CAA certification	Begin 1981

Two prototypes are currently undergoing flight testing. P2 is flying at MBB; P3 is flying at KHI. The test program which was worked out jointly and approved by the authorities is shared by the companies.

The handling characteristics proved to be as expected and very similar to those of the BO 105. As far as the performance data are concerned, there is already an indication that the helicopter will meet or even exceed the estimated values. The flight test program as well as the bench tests and tie-down tests are continuating.

6. Work Sharing and Program Management

Generally the work sharing for development and production is identical; (see fig. 23). Each company produces the self-developed parts / components for all future produced helicopters. Each company will take the cost for its development part. For this reason there is no cash flow between the two companies. The MBB participation is sponsered by the Bundesministerium für Wirtschaft (German Ministry of Economy) similar to other commercial aircraft programs.

6.1 MBB Share

- Configuration and program management
- Integration of systems
- Rotor blade
- Rotor head
- Tail rotor
- Tail rotor drive system
- Upper controls
- Hydraulic boost
- Empennage
- Tail boom
- Mission equipment
- Rotor whirl tower testing
- All BO 105-identical components and subsystems
- Static and fatigue testing of MBB-parts
- Loads and performance calculations
- Aeroelasticity
- Handling qualities
- Proportionate final assembly
- Flight testing of P2 and S01
- Type investigation for LBA, FAA and CAA certification.

6.2 KHI-Share

- Main transmission
- Mechanical controls
- Center fuselage
- Cockpit
- Engine installation
- Fuel and oil system
- Electrical system
- Instrument installation
- Landing gear
- Cabin interior
- General equipment
- Structural testing of prototype P4
- Transmission testing at KHI transmission test stand
- Wind tunnel tests
- Proportionate final assembly
- Static and fatigue testing of KHI-parts
- Flight testing of P3
- Type investigation for JCAB certification.

6.3 Program Management

Initially there was some scepticism as far as program management is concerned. Problems had been expected caused by the long distance between the two companies. In order to guarantee an efficient management system and a quick progress, special attention was directed to this area.

A general program office was arranged at MBB with participation of KHI representatives. This office is coordinating the activities of both development teams. All exchange of informations is done via this office.

The detail specifications defined during the preliminary design phase are continuously updated and harmonized. Special interface specifications and interface drawings are used in order to avoid any fitting problems. Informative drawings are continuously exchanged. For this purpose micro films have been sent by air mail; thus offering a minimum delay.

Liaison engineers were exchanged, being responsible for the information flow.

A management handbook was worked out especially for the BK 117 project and is in use by both companies. This handbook covers the following major items:

- Design instructions which define the basic rules for design of the essential components
- Guidelines for design
- Rules for decision finding
- Selection of materials; guidelines for the selcetion of materials as well as a list of materials to be used including the material data
- List of applicable standards
- Manufacturing processes
- Qualitiy control procedures.

The most important means of coordination proved to be the direct communication by telephone and telex. The 8 hours of time difference between Japan and Germany leaves just enough time overlap for communication during office hours. Sometimes the time difference is even an advantage, giving the possibility for each partner to answer overnight.

Direct contacting in a joint program is mandatory. Due to this fact engineering meetings lasting one to two weeks are held 4-times annually alternatively at MBB or at KHI.

The type investigation program is coordinated by the general program office supported by certification meetings with participation of LBA and JCAB officials.

7. Concluding Remarks

With the beginning of the flight testing a first important milestone is reached. It might already be concluded that the design objectives are met. The desired commonality with the BO 105 could be accomplished without the necessity to accept compromises penalising the BK 117. This can easily be checked by comparing the BK 117 data with other helicopters of the same class. The flight test and type investigation is progressing on schedule. Design efforts are already directed to production preparation.

The members of the MBB-team as well as those of the KHI-team are convinced of the success of the BK 117 program. Both teams are looking forward to a long and productive cooperation.

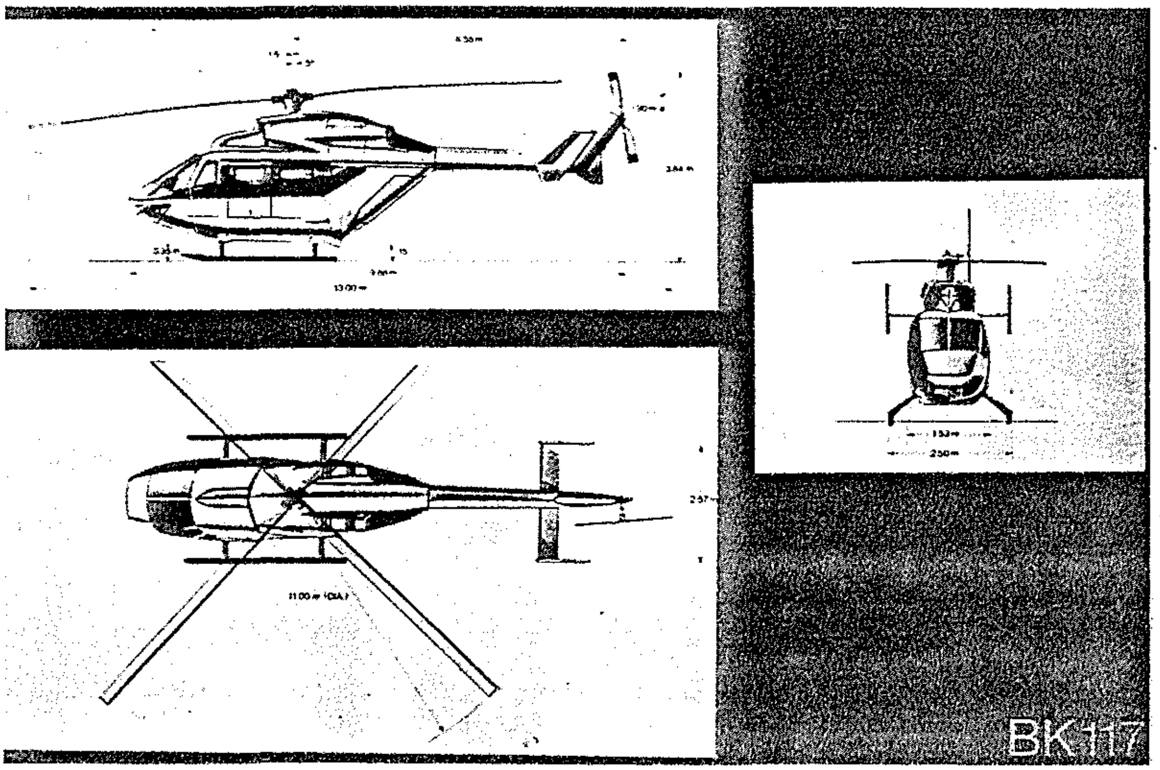

Fig. 1: BK 117 Three-View Drawing

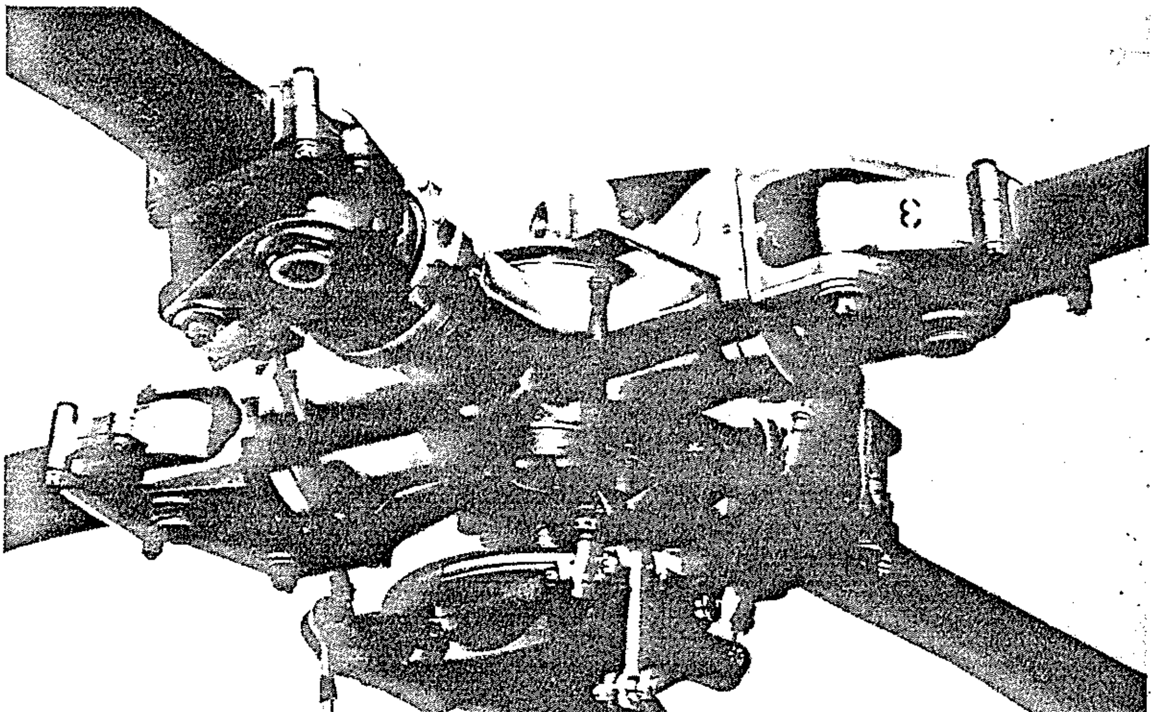

Fig. 2: Rotor System

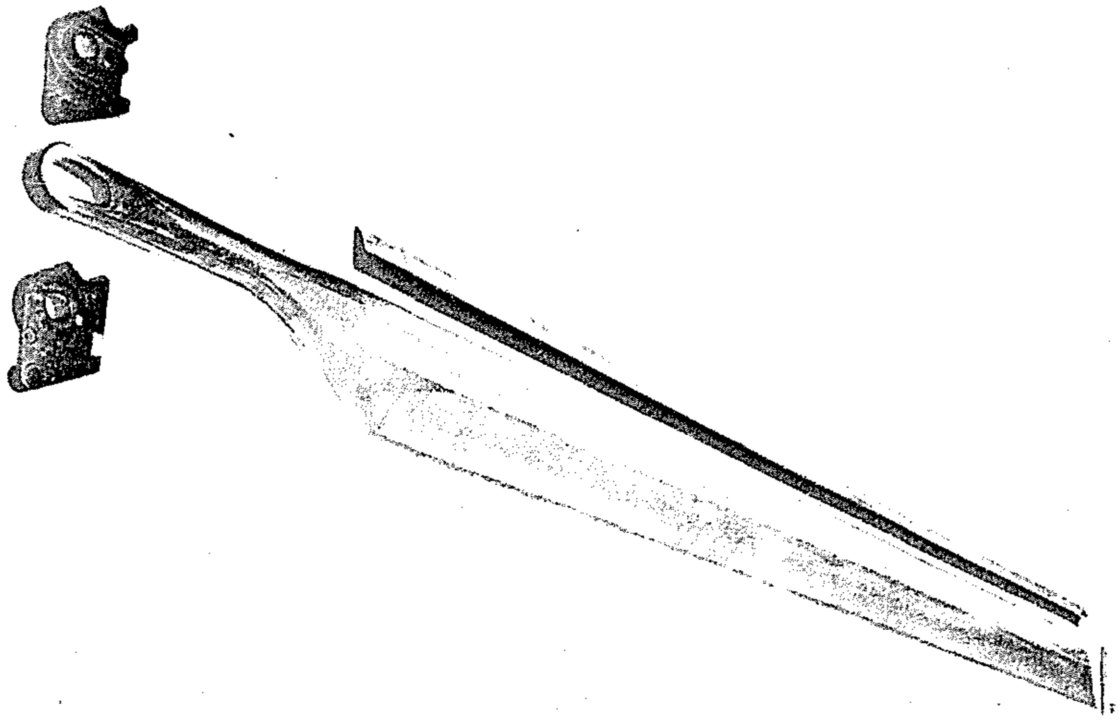

Fig. 3: Main Rotor Blade

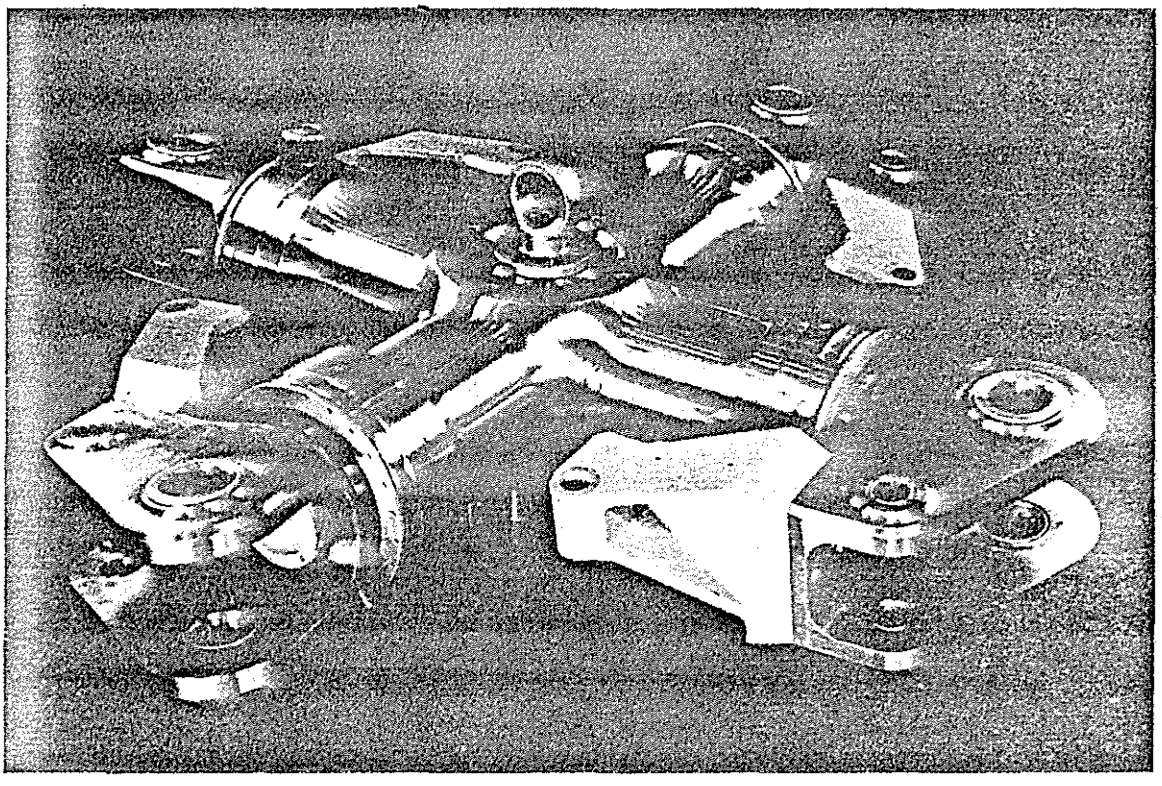

Fig. 4: BK 117 / BO 105 Rotorhead Assembly

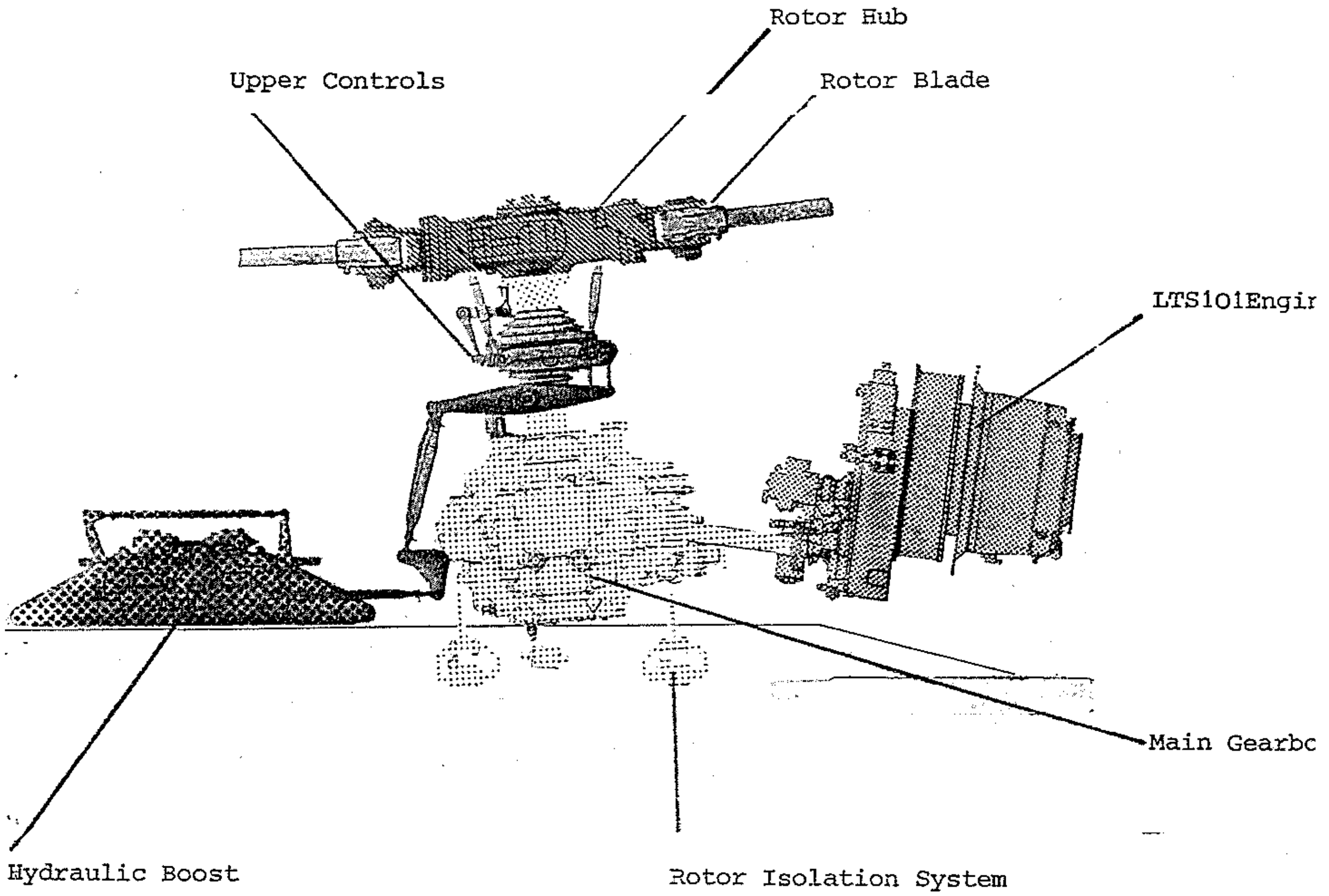

Fig. 5: Installation of the Dynamic System

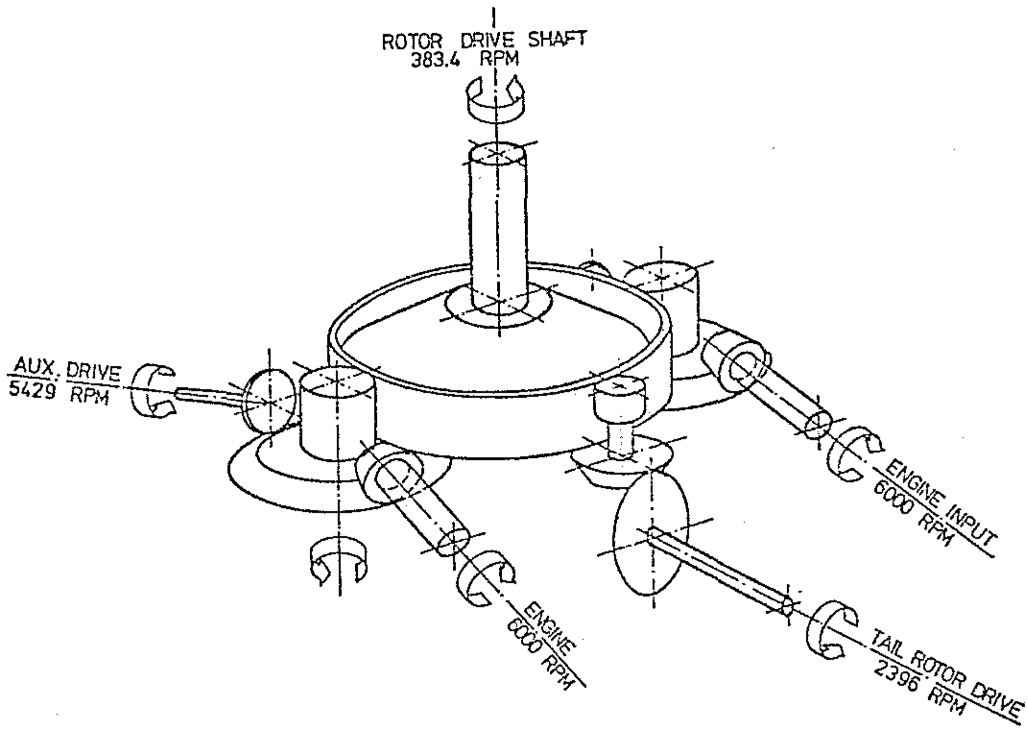

Fig. 6: Main Gearbox Schematic

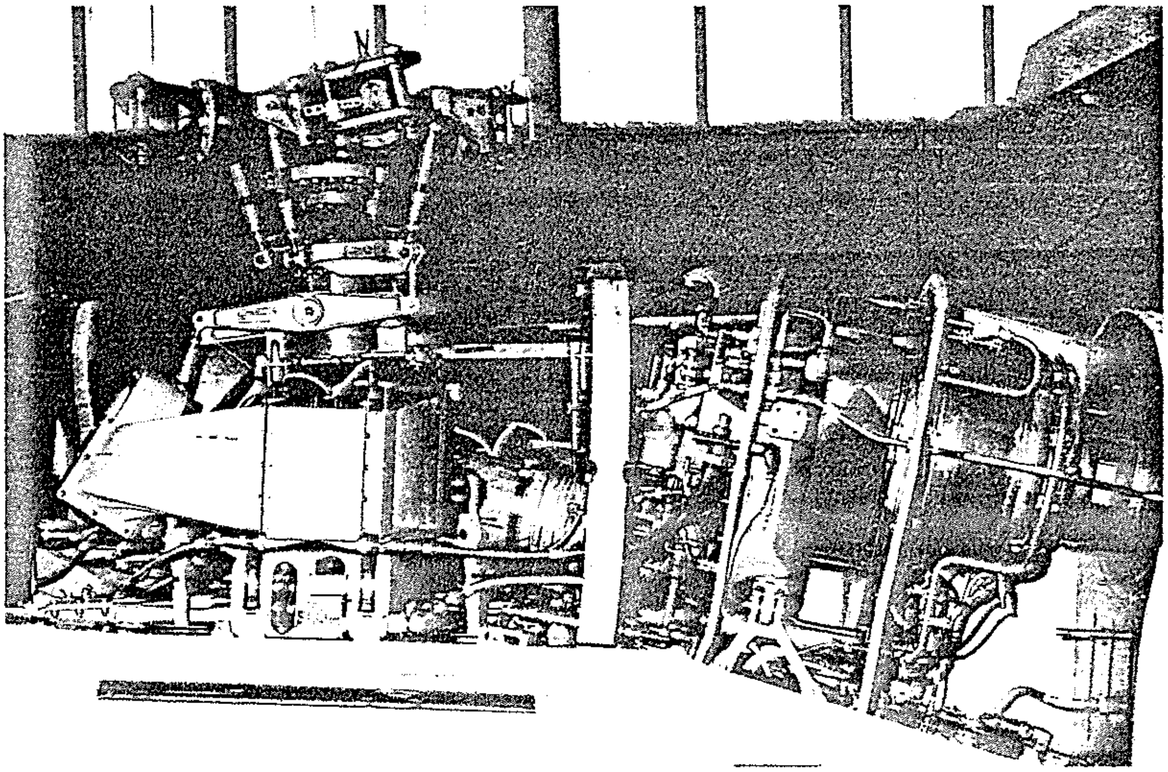

Fig. 7: Dynamic System Installation

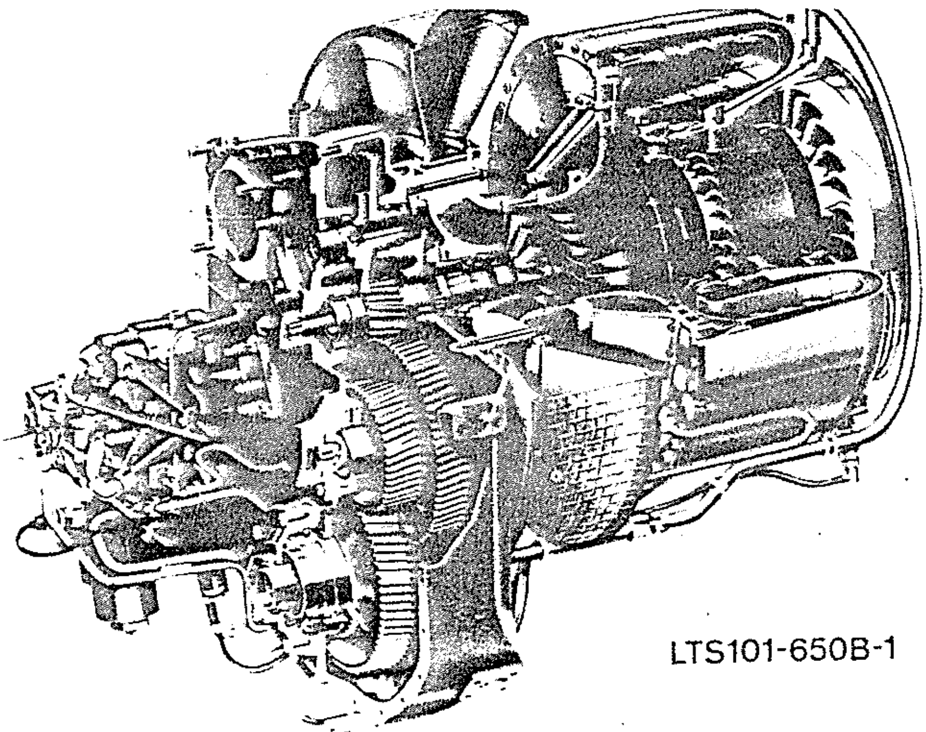

Fig. 8: AVCO-LYCOMING LTS-101-650B-1 Engine

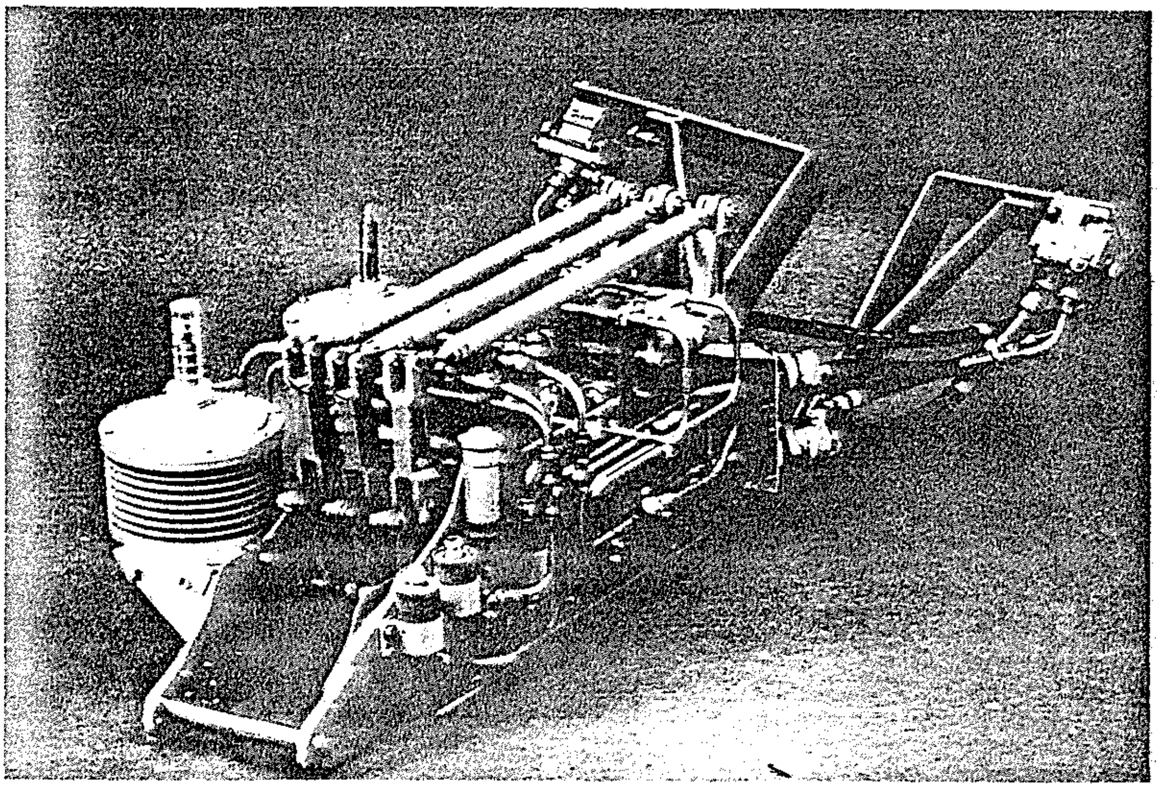

Fig. 9: Hydraulic Boost System

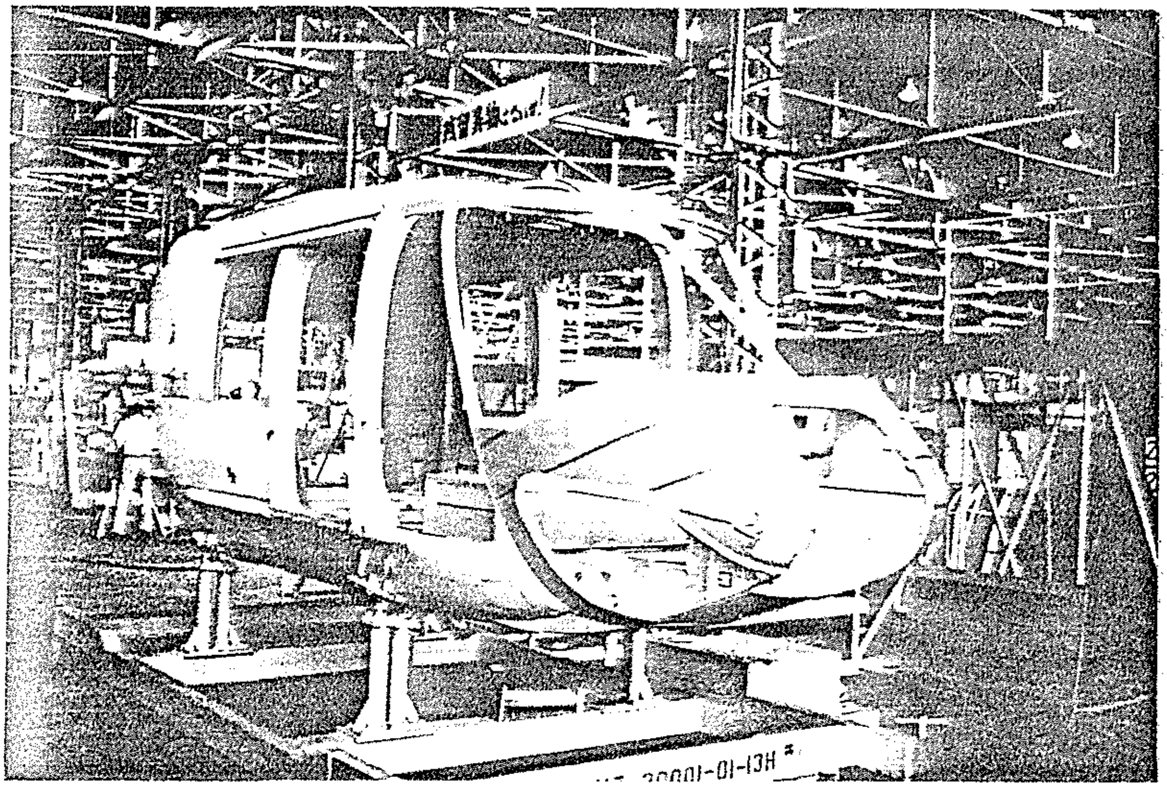

Fig. 10: Fuselage Structure

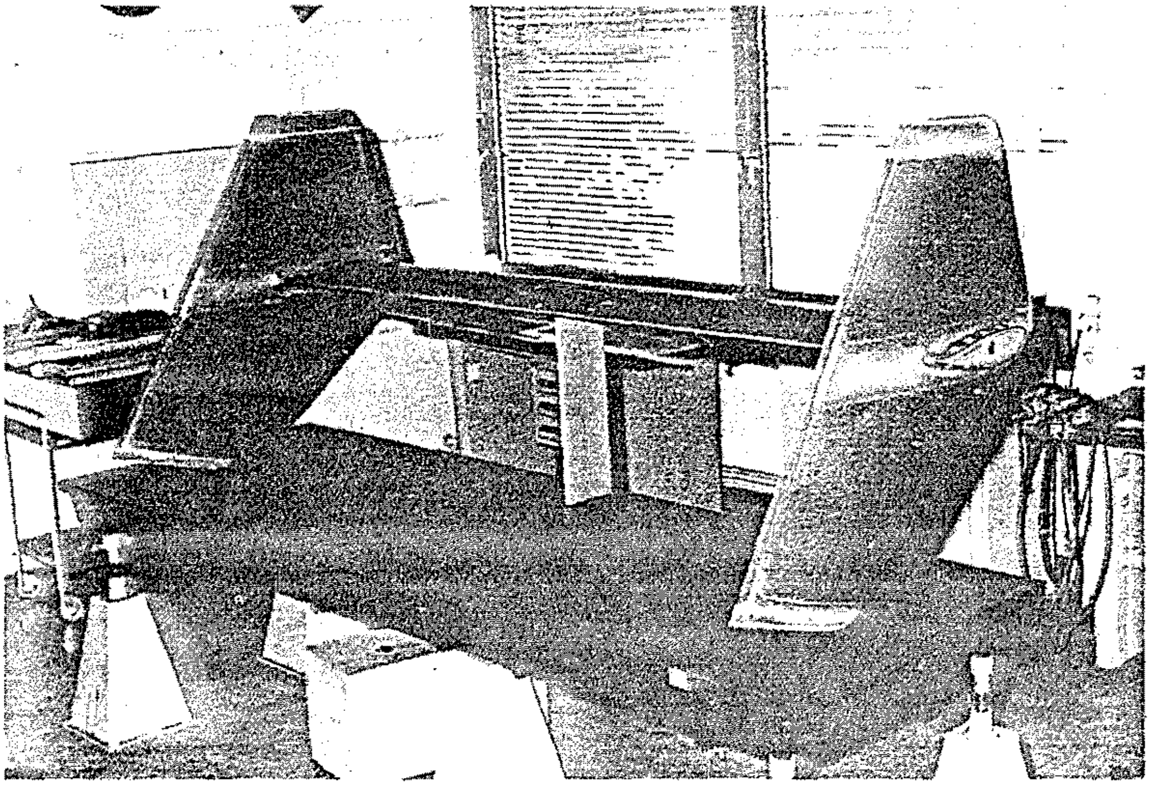

Fig. 11: Horizontal Tail and End Plate Assembly

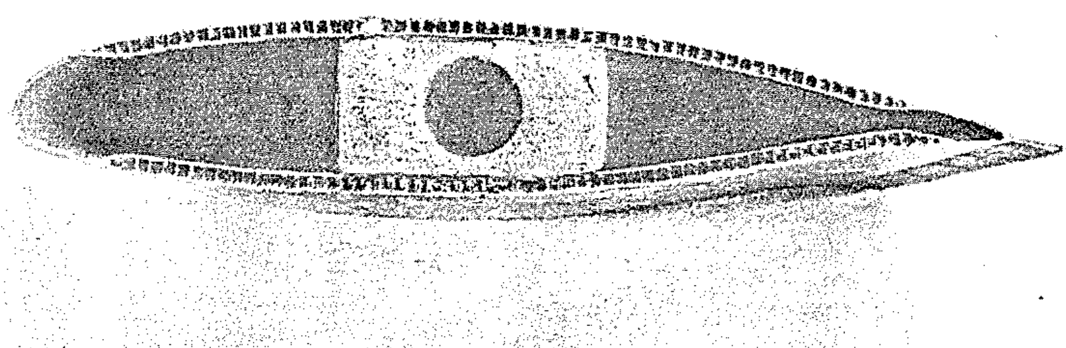

Fig. 12: Cross Section of Horizontal Tail

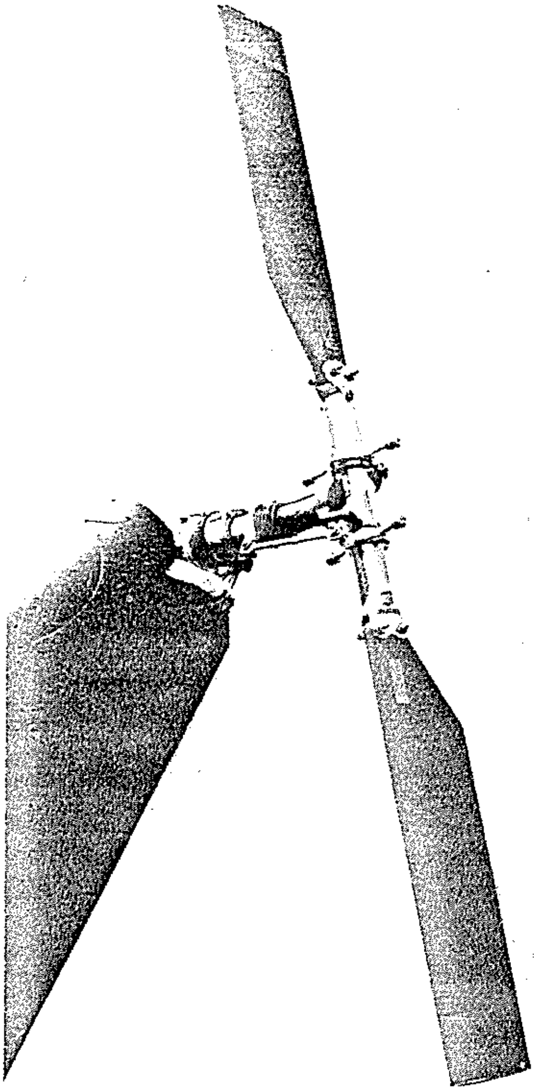

Fig. 13: Tail Rotor

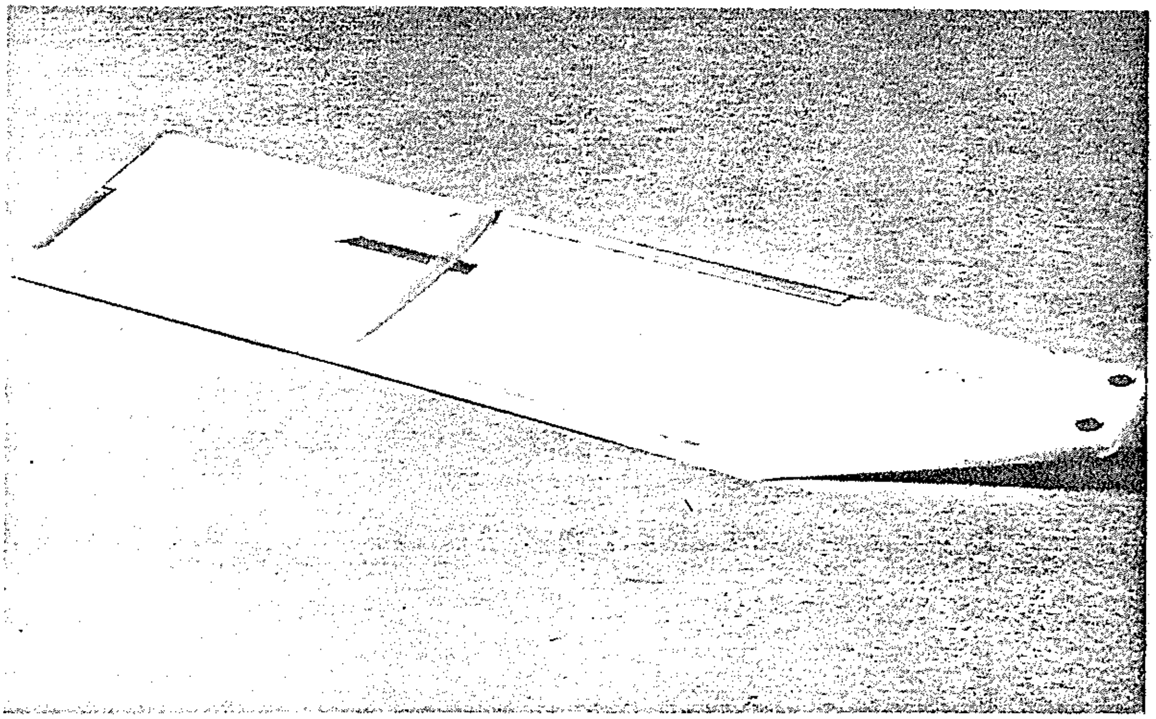

Fig. 14: Tail Rotor Blade

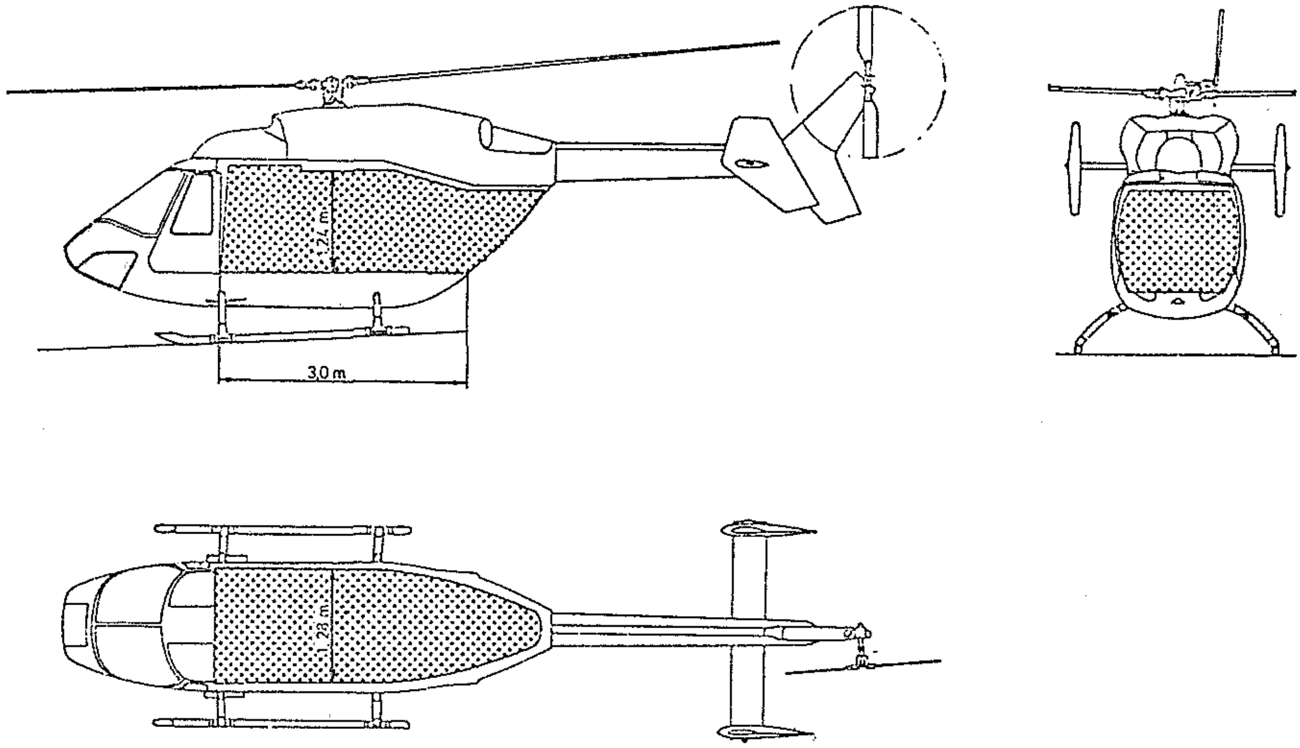

Fig. 15: Passenger/Cargo Compartment

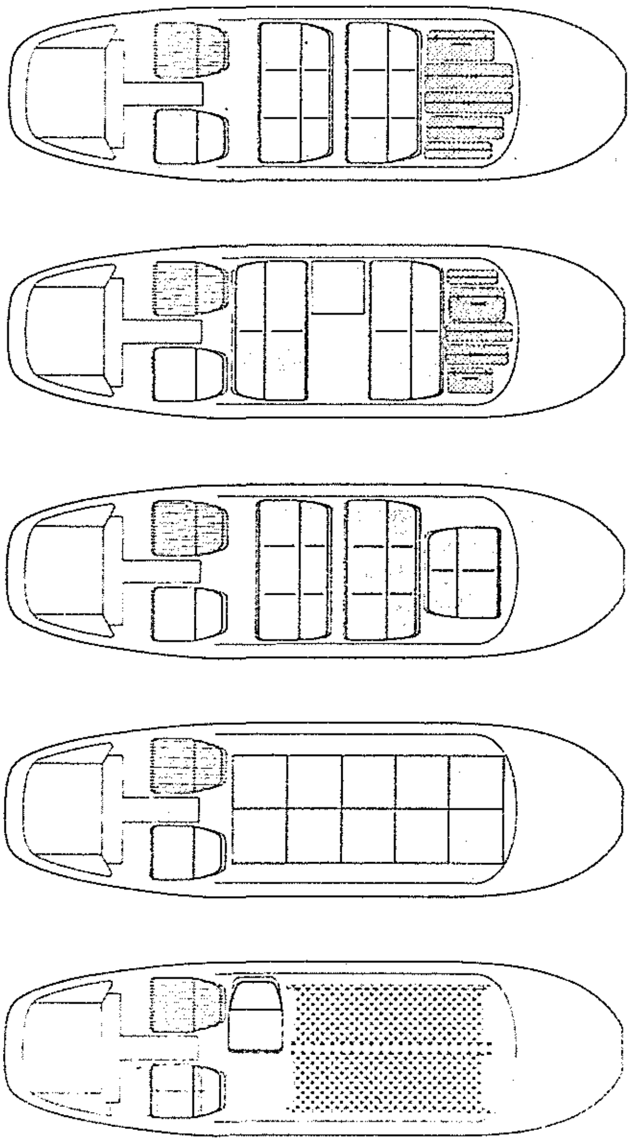

Fig. 16: Some Possiblities Seat Arrangements

Fig. 17: Cockpit / Cabin Access through Side Doors

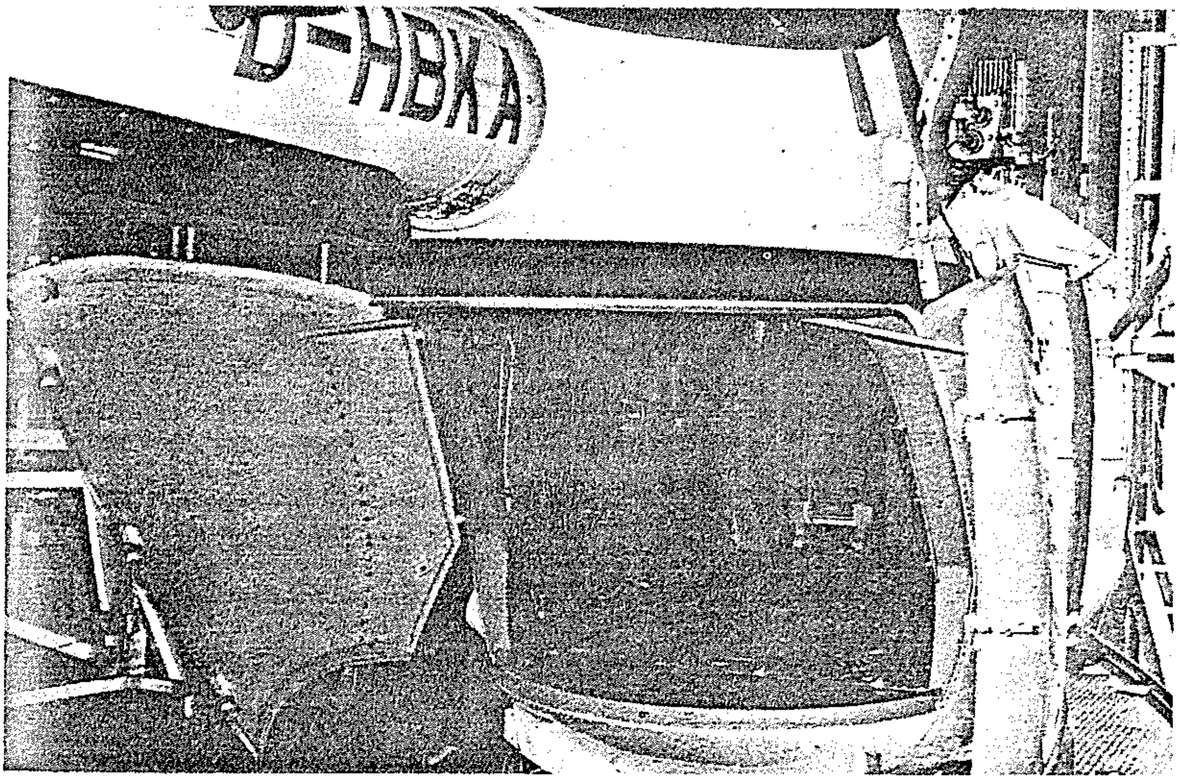

Fig. 18: Cabin / Cargo Room Access through Rear Doors

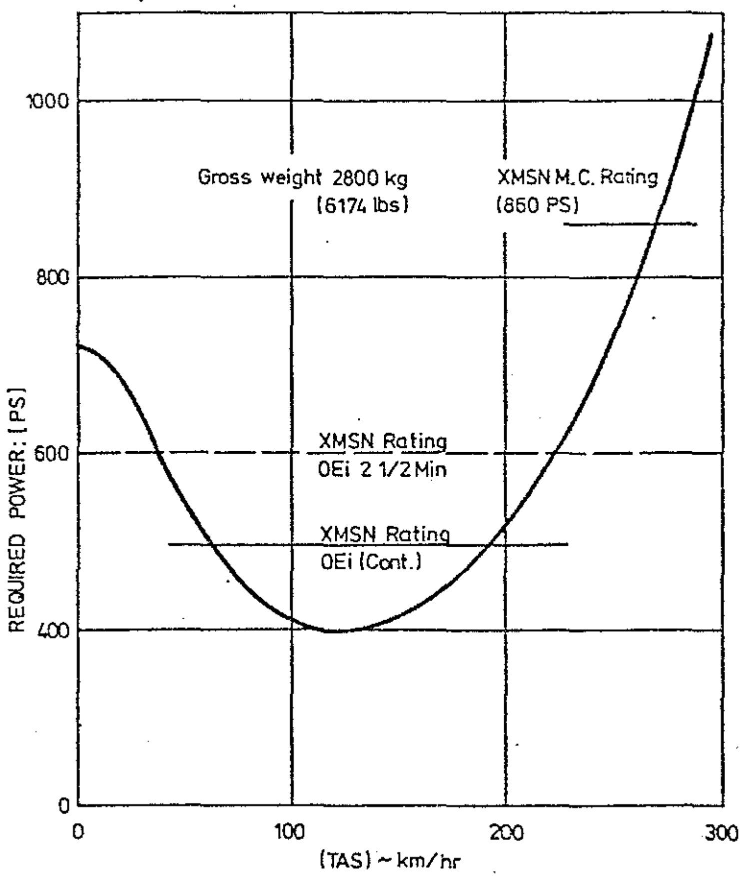

Fig. 19: Powe
required VS Sp
(SL STD)

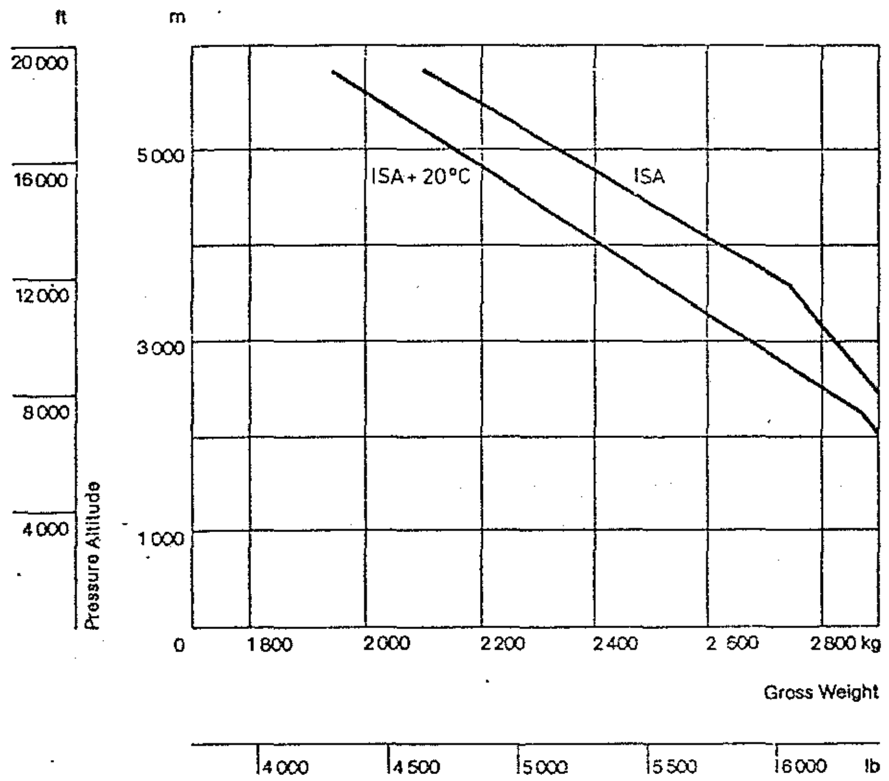

Fig. 20: Hover OGE Ceiling VS Weight
Take-off Power

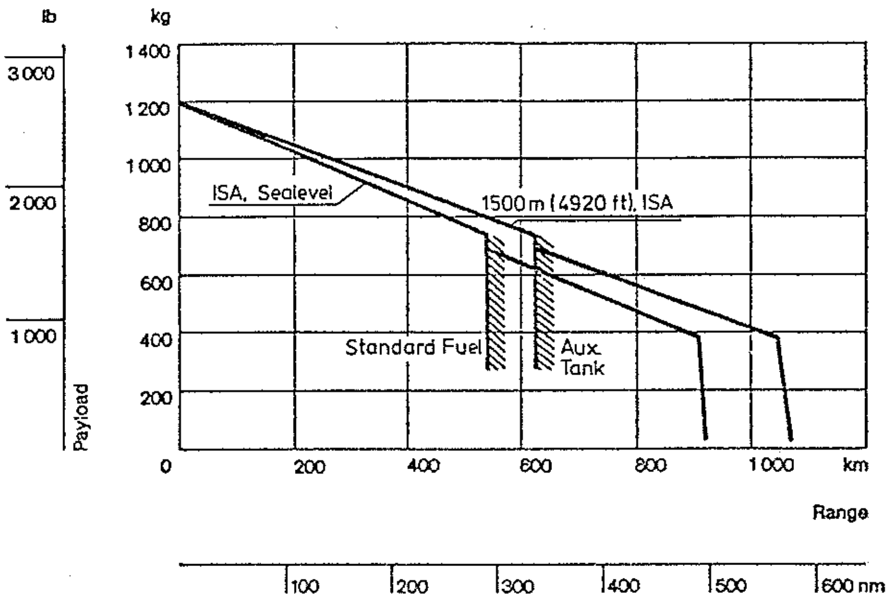

Fig. 21: Payload VS Range

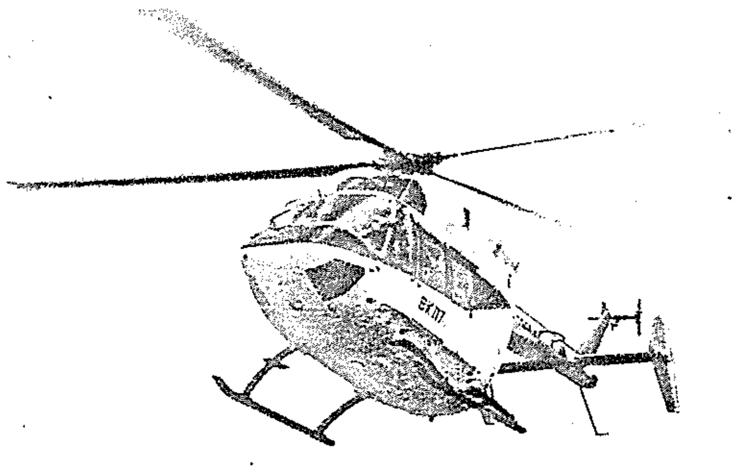

Fig. 22: BK 117 During First Flight

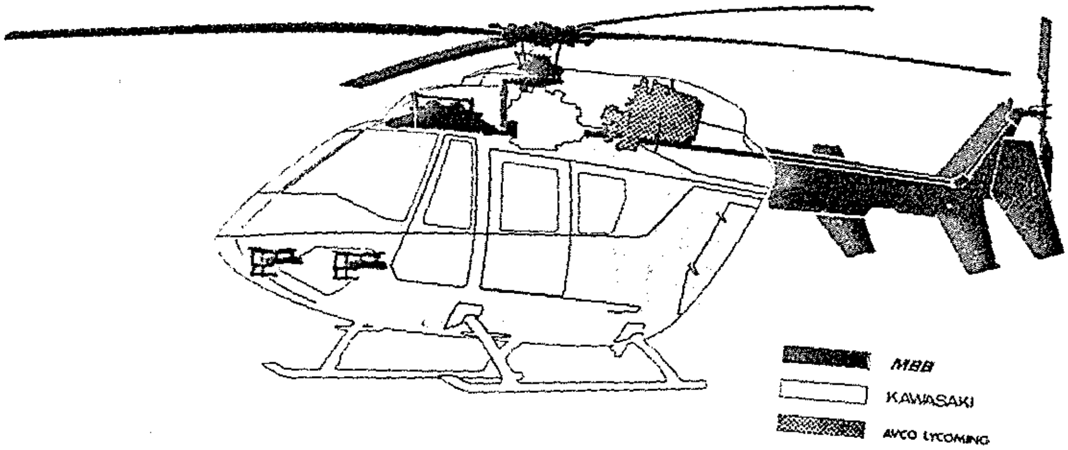

Fig. 23: KHI - MBB Work Sharing