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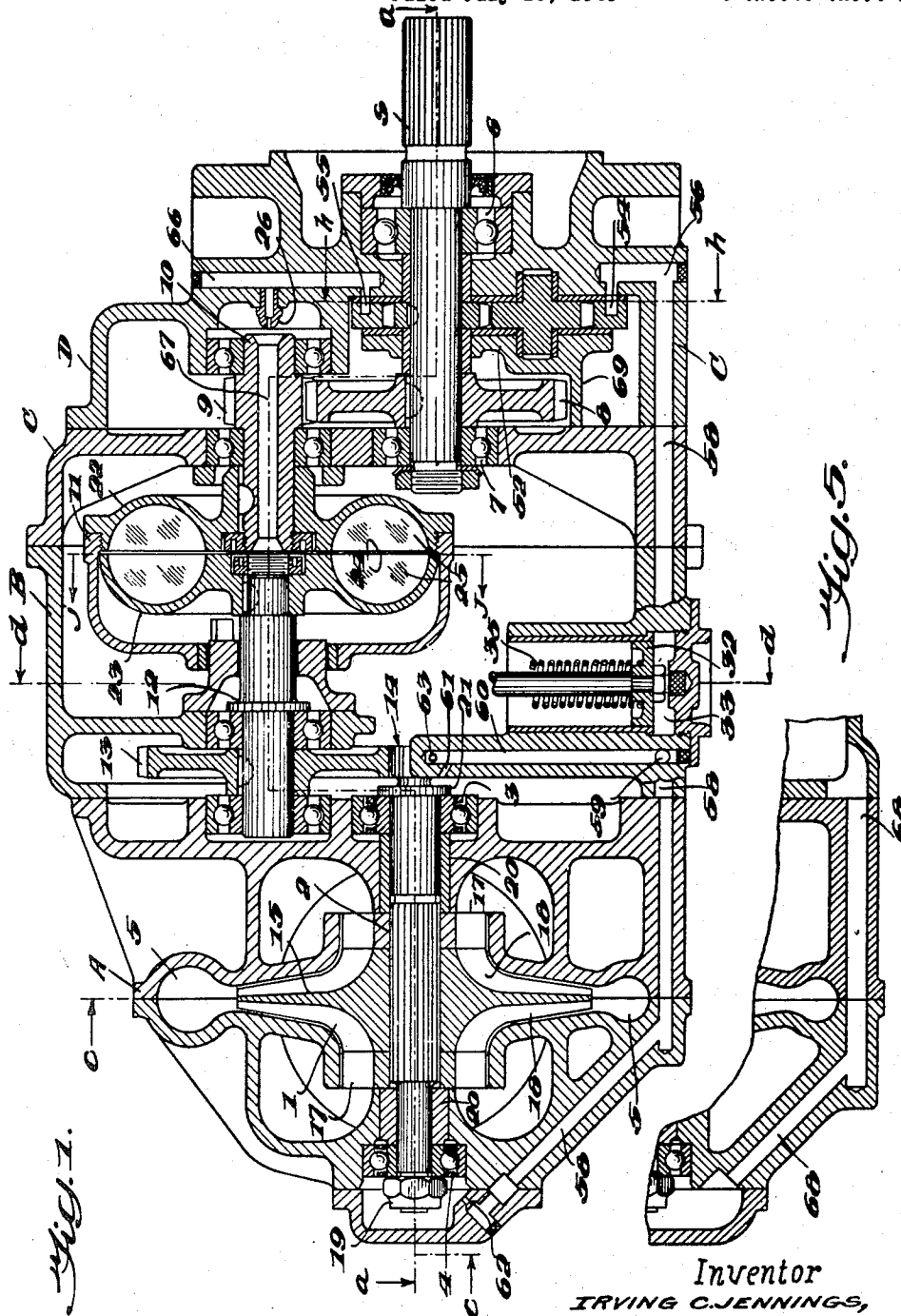
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2,425,885

CENTRIFUGAL COMPRESSOR

Filed July 16, 1943

4 Sheets-Sheet 1



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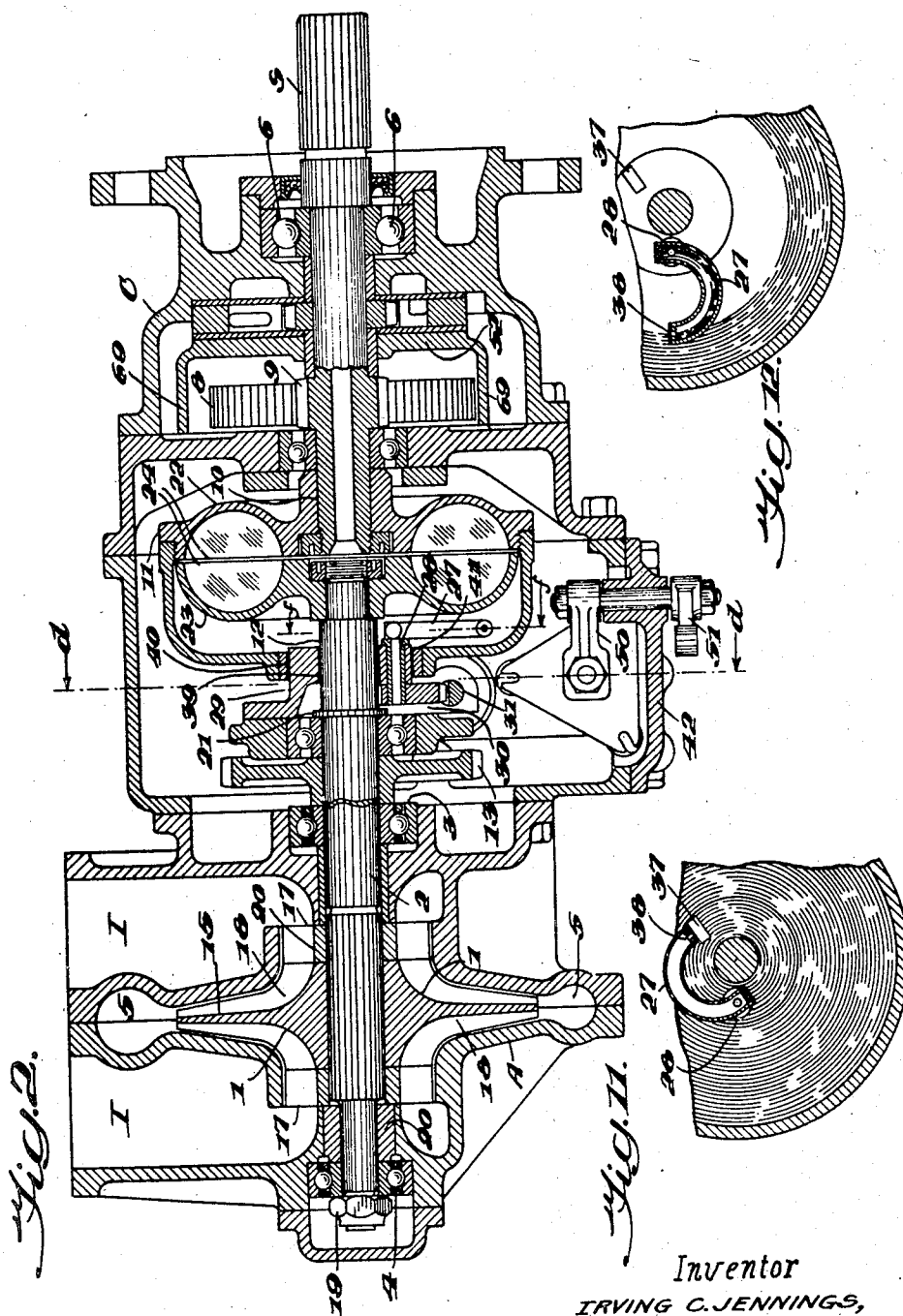
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4 Sheets-Sheet 2



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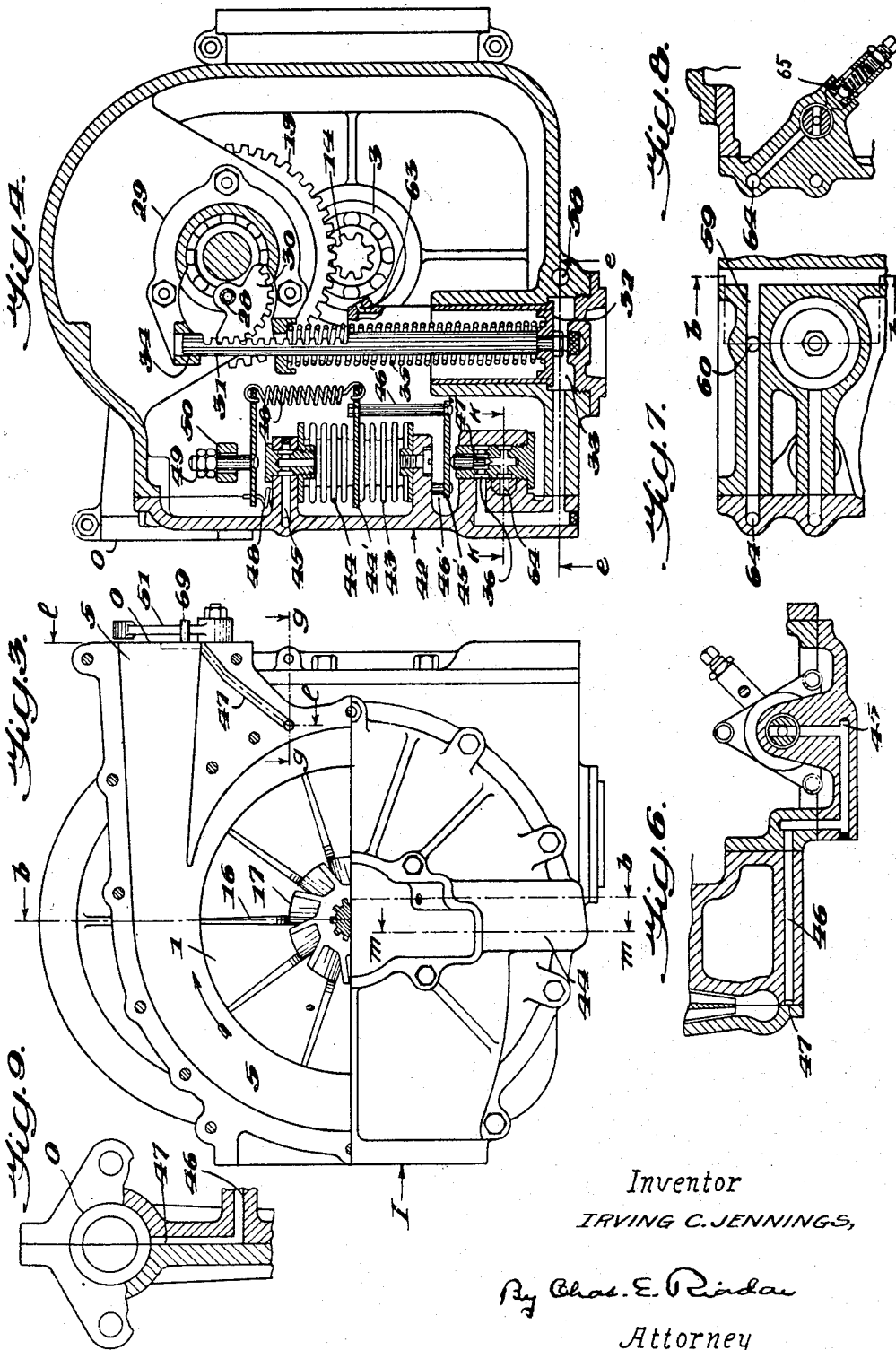
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4 Sheets-Sheet 3



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Fig. 14.

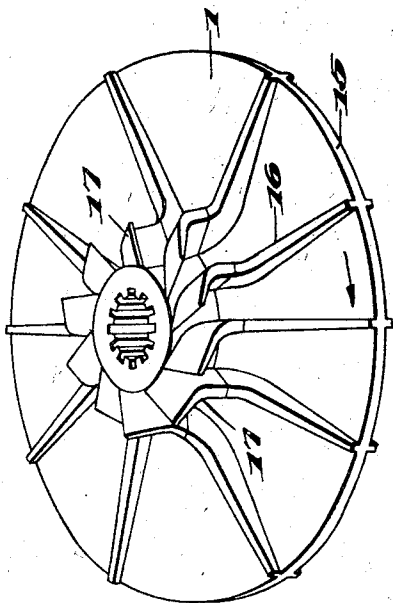


Fig. 15.

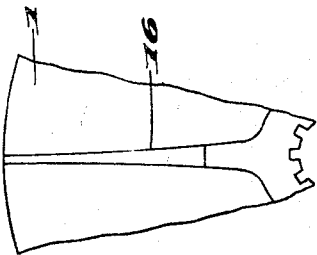


Fig. 13.

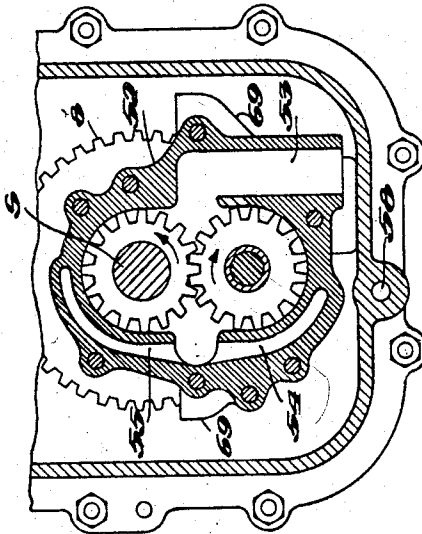
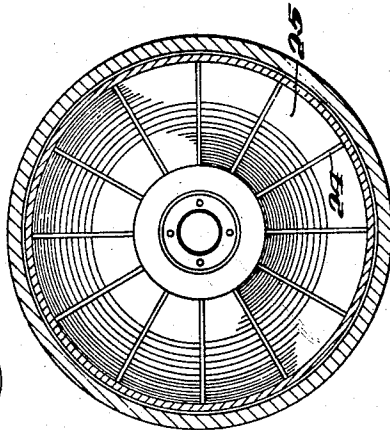


Fig. 10.



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UNITED STATES PATENT OFFICE

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CENTRIFUGAL COMPRESSOR

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Application July 16, 1943, Serial No. 495,047

13 Claims. (Cl. 230—11)

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This invention relates generally to a centrifugal compressor designed for an airplane cabin supercharger. It will be understood that the same device could readily be used for supercharging an internal combustion engine or generally for compressing air or producing a vacuum.

Centrifugal compressors for air or gases have the advantage of simplicity, compactness, and durability. Their design, however, heretofore has been limited to conditions where low pressure differentials were required, except in large capacity, multi-stage units, which are heavy and cumbersome. This made them unsuitable for supercharging airplane cabins for higher altitudes, where a relatively small amount of air at a relatively high differential pressure had to be handled. Also, for such applications this type of compressor requires an elaborate, cumbersome type of control to take care of the varied conditions resulting from the great change in density of the air when the plane is near the ground or when it is operating high above the earth.

One of the principal objects of the present invention is the construction of a centrifugal compressor and control which obviates all of the disadvantages above set forth.

The present invention consists of a centrifugal compressor and control capable of handling small amounts of air at a relatively high differential pressure. It is very compact and requires very little horse power to operate.

These results are accomplished by the use of a small diameter impeller running at a much higher speed than has heretofore been thought possible. This makes the compressor very small and light and adds greatly to its efficiency, as the unavoidable leakage and the skin friction or drag of the impeller is greatly reduced due to its small diameter.

In order to run at these high speeds the impeller must be absolutely symmetrical. It is made of the strongest and lightest material, with both blade and central web sections narrowed from the hub to the periphery to develop uniform strength to resist the high centrifugal forces present. It is preferably of the open type, with radial blades in close running relation to the casing.

The impeller is preferably mounted on a shaft supported by ball bearings on each end. These bearings, and the high speed gear, are provided with novel means for cooling and lubrication to permit running at the extremely high speed required.

To obtain the high impeller rotation necessary,

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double reduction gearing with an intermediate shaft is preferably used. The intermediate shaft is run at four or five times the speed of the drive shaft, and the impeller is operated an equal amount faster than the intermediate shaft, giving an overall speed-up ratio in the order of say 25 to 1, or an impeller speed of approximately 70,000 revolutions per minute when the diameter of the impeller is about $4\frac{1}{2}$ " and the main drive is running at about 2800 R. P. M.

Part of the invention resides in the type of speed control provided, which consists of a hydraulic coupling, known to the art as a fluid drive, mounted on the intermediate shaft or the high speed shaft and provided with an automatic device built into the compressor casing which alters the speed of the compressor inversely as the density of the air handled by regulating the fluid level in the coupling. This fluid coupling has a damping effect on the vibrations set up by the high speed gearing and allows a greater degree of misalignment.

Oil pressure for operating this control, including the supply of oil to the interior of the fluid coupling to restore the liquid level in the coupling and to take care of leakage through the seals and to lubricate and cool the bearings and gears, is supplied by an oil pump, preferably mounted directly on the low speed or main drive shaft.

In an airplane, where vibration is always present and reliability is very important, separate oil pipes and pipe couplings are to be avoided. The invention is designed without any of these appendages. The passages for oil and the passages to transmit the cabin air pressure to the control are drilled or cast in the structure and matched at the joints to form through conduits. There is no danger of compressor failure due to broken auxiliary piping. The design is such that the various parts of the casing can be readily disassembled.

In the drawings wherein like reference numerals indicate corresponding parts in each of the several views,

Fig. 1 is a longitudinal section of the invention, taken along the lines b—b of Fig. 3 and Fig. 7.

Fig. 2 is a section through the compressor along the lines a—a, Fig. 1, looking downward.

Fig. 3 is a view looking toward the end of the compressor opposite drive end, the upper half being in section along the lines c—c, Fig. 1.

Fig. 4 is a section along the lines d—d, Fig. 1 and Fig. 2, showing details of the automatic control device.

Fig. 5, along the lines m—m Fig. 3; Fig. 6, along

the lines *g-g* Fig. 3; Fig. 7, along the lines *e-e* Fig. 4; Fig. 8, along the lines *k-k* Fig. 4; and Fig. 9, along the lines *l-l* Fig. 3, show details of the control and the control and lubricating piping.

Fig. 10 is a section through the fluid coupling along the lines *j-j*, Fig. 1.

Figs. 11 and 12 are sections through the fluid coupling along the lines *f-f*, Fig. 2, showing different positions of the oil level regulating scoop.

Fig. 13 is a section through the lubricating oil pump along the lines *h-h*, Fig. 1.

Fig. 14 is a view of the impeller in perspective, illustrating the construction of axial and radial blades.

Fig. 15 is a view of one blade of the impeller showing the curved section.

In the drawings, A is used to indicate the centrifugal compressor; B the intermediate structure containing the speed control and part of the fluid drive, and part of the speed-up gearing; C and D are the structures containing the remainder of the gearing, the lubricating pump, and the main drive shaft S. I (Fig. 2) indicates the air inlet, and O (Fig. 3) the air discharge.

I is the impeller, preferably double suction, splined and mounted on the shaft 2, which is supported by ball bearings 3 and 4. It revolves in a close fitting surrounding casing expanding into a volute passage 5 terminating in the discharge pipe O. The impeller is driven through step-up gearing from main drive shaft S, which may be connected to an engine of the airplane or to other prime mover. The shaft S is supported by ball bearings 6 and 7. On this shaft is mounted a gear 8, which meshes with a pinion 9 on an intermediate shaft 10. This shaft, supported by suitable bearings, is connected through a fluid drive coupling 11 to a shaft 12, also supported by bearings, on which is mounted a gear 13 meshing with the pinion 14, which is preferably machined directly on the shaft 2.

The impeller is shown in section in Figs. 1 and 2; in the end view Fig. 3; in perspective in Fig. 14, and one of the blades is shown enlarged in Fig. 15. It will be noted that the impeller is perfectly symmetrical both around its transverse and longitudinal central axes. The central web 15 and the radial blades 16 are made relatively heavy in section near the hub and are then gradually curved to a narrow width at the periphery so as to equally stress all parts of the impeller when it is subjected to centrifugal force. This makes the most economical use of material. By making the web and blade sections narrow at the periphery, their weight at this point is reduced, which greatly reduces the centrifugal force, which, with the heavier blade section near the hub, gives the necessary strength and permits the impeller to be run at extremely high speed. The impeller is preferably made of a very light, strong material such as Duralumin, forged to obtain the greatest strength, and then machined to the proper shape.

The impeller is further provided with axial blades 17, which form inlet openings of equal area on each side of the impeller. These blades are shaped to form an acute angle with the direction of rotation to scoop in the air without shock and are then curved to smoothly match the radial blades of the impeller. This double inlet eliminates axial thrust and permits small diameter inlet openings relative to the diameter of the impeller, which adds to the efficiency.

The axial blades and the radial blades are closely surrounded by the casing, the walls of which are gradually curved and tapered to form passages 18 to conduct the air with a minimum loss of head smoothly through the impeller into the volute 5.

The axial blades are shown as separate pieces splined to the shaft 2 and clamped against the impeller by means of the nut 19 through bushings 20, the inner races of ball bearings 3 and 4, and a shoulder 21 of the shaft 2. It will be readily understood, however, that the axial blades could be integral with the impeller.

The operation of the fluid coupling 11 will be readily understood from Figs. 1, 2, 10, 11 and 12. It consists of a driving member 22, which is preferably mounted on the intermediate shaft 10, and a driven member 23, which is mounted on the shaft 12. Members 22 and 23 are separated from each other only by a running clearance and their axes of rotation approximately coincide. Each member is provided with radial blades 24 forming buckets 25, with curved bottoms. When the coupling is filled with liquid and the driving member 22 is rotated rapidly, the liquid acquires the velocity of the driving member and liquid is circulated by centrifugal force around the bottom of these buckets into the buckets of driven member 23, causing this member to acquire a velocity approaching that of the driving member. Under these conditions the coupling is transmitting the maximum power, and very little slip occurs between the driving and driven members. If the liquid is partially removed from the coupling when under load, the driven member will run at a slower speed than the driving member, the difference in speed depending on the amount of liquid removed. When all the liquid is removed no motion will be transmitted between the driving and driven member. This action of fluid couplings, which is well understood in the art, is used to control the speed of the compressor.

The horsepower output of a fluid coupling varies about as the cube of the speed. By placing this coupling on the intermediate shaft or on the high speed shaft, both of which are running at high speed, the size of this coupling is greatly reduced.

Oil is the preferred liquid to use in the fluid coupling as it is non-corrosive and may also be used to lubricate the moving parts.

Details of the control are as follows: Oil is fed into the interior of the coupling continuously in a small amount through an orifice 26 and the hollow shaft 10. A curved pipe or scoop 27 is mounted on a hollow shaft 28, which is journaled in a stationary housing 29. On the shaft 28 is fixed a segment of gear 30, which is in engagement with a rack 31. The rack 31 is attached to a piston 32 in a cylinder 33 and is supported on the other end by a bearing 34. The piston 32 is raised by oil pressure and is lowered by the spring 35 when the oil pressure is released. The oil pressure is regulated by a valve 36 controlled by automatic means responding to the absolute pressure in the cabin. Reciprocating the piston up and down causes the end of the scoop 27 to move in and out from the center of the coupling.

The scoop, being connected to hollow shaft 28, will remove any liquid in the coupling as long as its end is submerged, because it is stationary and is presented at an angle to the rapidly revolving liquid in the coupling. An orifice 38 is provided in the end of the scoop to limit the rapidity with which the liquid is removed.

In Fig. 11 the scoop is shown at its position nearest the center, where it has the least scoop action. It would continue to remove a certain amount of liquid in this position but for the fact that it is in close proximity to a stop 37, which effectively seals its end. In this position the coupling will be kept completely filled with liquid, due to the continuous supply of oil which is introduced at a rate somewhat in excess of the leakage along the clearance spaces 39 and 40 between the coupling hub and the stationary piece 29, and 41 along the bearing clearance of the hollow shaft 28. Under this condition the coupling develops its full power and the compressor is running at its maximum speed. The automatic means for thus regulating the speed of the compressor, in addition to the oil control valve 36, consists of the following parts. All of these parts are mounted on detachable part 42 of the casing B so that they can be readily removed for repair or replacement. Above the valve 36 are fixed two flexible bellows 43 and 44, separated by a plate 44'. A plate 45', fixed to the plate 44' by three posts 46', rests on the valve stem 47' of the valve 36.

The bellows 43 has been exhausted of air so that its interior has a pressure of approximately zero absolute. The bellows 44 is connected through passages 45, 46 and 47 (Figs. 3, 4, 6 and 9) to the discharge O of the compressor, which in turn is connected to the supercharged cabin. The force exerted by the bellows 44 in pounds will be substantially the absolute pressure of the supercharged cabin times the area of the end of the bellows, as this area is relieved of all pressure by the bellows 43.

Springs 48, the tension of which may be adjusted by the nuts 49, compress the bellows 44 against the absolute cabin pressure, and if this pressure is insufficient the control valve 36 will be opened by oil pressure from a pump or other source of supply and oil under pressure will be built up in the cylinder 33. Piston 32 will be forced upwards, the scoop 27 will be retracted from the periphery of the coupling, oil coming in through the discharge nozzle 26 will rapidly fill up the fluid drive 11, which will then have less slip, the compressor will increase in speed, and more air will be delivered.

When the cabin pressure rises to the predetermined amount, the bellows 44 will be expanded and the plate 45' will force the valve stem 47' against its seat, and the valve 36 will be closed. Leakage between the piston 32 and the cylinder 33 will permit the spring 35 to force the piston downward, which will extend the scoop 27 out further toward the periphery of the coupling. The oil will be scooped out of the revolving coupling by the scoop 27, and the compressor will slow up and furnish less air.

An arm 50 fixed on a shaft, to which is fastened a lever 51, is provided to increase manually the tension of the springs 48, if it is desired to increase the air discharge of the compressor. Stops 69 are provided to limit the travel of the lever 51.

The oil under pressure for operating the piston 32 for the continuous supply to the interior of the fluid coupling and for cooling and lubricating the bearings and gears of the compressor, is supplied by a special oil pump 52 (Figs. 1 and 13). It is shown preferably as a gear type pump mounted directly on the slow speed main drive shaft S. It takes its oil from the bottom of the gear casing through an inlet passage 53 and discharges the oil under a moderate pressure into the passages 54 and 55. Passage 54 opens directly into the

passage 56, which connects through a passage 58 to a passage running right through the compressor. The passage 58 conducts the oil into passage 59 and 60 (Fig. 7) into orifices 61 and 62, which furnishes a spray of oil directly on the cages of the ball bearings 3 and 4, and to the orifice 63, Figs. 1 and 4, which sprays the oil on to the high speed pinion 14.

The oil passage 60 is preferably formed in a post which is attached to one side of the cylinder 33, both post and cylinder being cast integral with the casing B. This construction provides a rigid support for the orifices 61 and 63.

The passage 59 also connects to the passage 64, (Figs. 4, 7 and 8), which supplies the oil to the speed control valve 36.

A relief valve 65 (Fig. 8), is provided to keep the oil pressure constant. The excess oil not used for lubrication and other purposes is discharged, falls to the bottom of the casing, and is returned to the suction of the oil pump.

Passages 55 and 66 (Fig. 1) conduct the oil to the orifice 26, which discharges it through a passage 67 in the center of the intermediate shaft 10 into the fluid coupling 11, to keep the coupling supplied continuously with oil.

The oil which is being returned from the fluid drive and from the orifices to lubricate and cool the bearings is all returned to the bottom of casing B, Fig. 1, and is again circulated by the gear pump 52. The passage 68 (Fig. 5), shows the means of returning the oil used to lubricate the bearing 4. It is understood that jets could be provided for the lower speed bearings and gears, but in view of the fact that there is a mist of oil continually present due to the spray being thrown by the high speed gear and from the oil returning from the fluid drive, this may be dispensed with.

The oil in the bottom of the casing is kept away from the gear 8 by a projecting wall 69 in the casing D (Figs. 1, 2 and 13), which makes a joint with the casing C, then extends up above the center line of the gear pump as shown in Fig. 13. This forms a trough around the lower part of the gear 8 and prevents the gear from throwing oil around the casing, and thus allows a deeper well of oil in the bottom of the casing.

While the valve 36 is shown as being automatically controlled by the absolute pressure in the cabin, it will readily be understood that it could be controlled by the volume or weight of air being handled by the compressor or by the absolute pressure of the inlet air or a combination of any of these, or other means, to satisfy some different condition.

Having thus fully described my invention, what I claim as new and desire to secure by Letters Patent of the United States is:

1. The combination with a high speed centrifugal compressor, of a drive means therefor including a fluid coupling, pump means for continuously supplying the fluid coupling with fluid to compensate for leakage, and scoop means controlled by the pressure delivered by said compressor for removing fluid from the coupling in varying amounts to produce slippage for regulating the output of the compressor, said scoop means being independent of said pump means.

2. The combination with a high speed centrifugal compressor and a drive means therefor including a fluid coupling, of pump means for continuously supplying fluid to said coupling, and pressure controlled means separate from said pump means for removing fluid from the cou-

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pling automatically in varying amounts to produce slippage for regulating the output of the compressor, said pressure controlled means including a bellows in communication with the discharge side of the compressor, an adjustable scoop automatically controlled by said bellows for transferring fluid from said coupling, said scoop being in the form of an arcuate tube having its discharge end pivotally mounted adjacent but to one side of the center of the coupling whereby its inlet end is movable from a position adjacent the periphery of the coupling to a position adjacent the center thereof, means for operating said scoop, said last mentioned means being controlled by the pressure delivered by said compressor.

3. The combination with a high speed centrifugal compressor and a drive means therefor including a fluid coupling, of pump means for continuously supplying fluid to said coupling, and means controlled by the pressure delivered by the compressor and separate from said pump means for automatically removing fluid from the coupling in varying amounts to produce slippage for regulating the output of the compressor, said pressure controlled means including a bellows in communication with the discharge side of the compressor, an adjustable scoop controlled automatically by said bellows for transferring fluid from said coupling, said scoop being in the form of an arcuate tube having its discharge end pivotally mounted adjacent but to one side of the center of the coupling whereby its inlet end is movable from a position adjacent the periphery of the coupling to a position adjacent the center thereof, and a stop for abutment with said inlet end to close the same when adjacent the center of the coupling.

4. In a unitary supercharging assembly including a driven shaft housing, a drive shaft housing, and an intermediate shaft housing, a high speed centrifugal compressor mounted in the driven shaft housing, step-up gearing for said compressor including a fluid coupling in the intermediate shaft housing, means including a pump in the drive shaft housing for supplying oil under pressure to said gearing and said fluid coupling, and means subject to the pressure developed by said compressor for regulating the effective volume of fluid in said fluid coupling.

5. The combination with a high speed centrifugal compressor including an impeller and a shaft for said impeller, of a drive shaft, power transmission means between said drive shaft and said impeller shaft, and including a fluid coupling, a casing for said power transmission means adapted to contain motive liquid for said coupling, a pump operated from said drive shaft for pumping the motive liquid from said casing, conduit means leading from the discharge side of said pump to continuously supply motive liquid to said fluid coupling, and means independent of said pump controlled by the pressure at the outlet of said compressor for automatically controlling the slip in said coupling to vary the output speed of said coupling.

6. The combination with a high speed centrifugal compressor and a drive means therefor including a fluid coupling, of pump means for continuously supplying motive fluid to said coupling, and pressure controlled means for removing fluid from the coupling in varying amounts to produce slippage for regulating the output of the compressor, said pressure controlled means including

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a bellows in communication with the discharge side of the compressor, and an adjustable scoop separate from said pump means and automatically controlled by said bellows for transferring motive fluid from said coupling to vary the slip in said coupling, and thereby vary the output speed of said coupling.

7. In a unitary supercharging assembly including a driven shaft housing, a drive shaft housing, and an intermediate shaft housing, a high speed centrifugal compressor mounted in the driven shaft housing, a step-up power transmission for said compressor including a fluid coupling and gearing in the intermediate shaft housing, means including a pump in the drive shaft housing for supplying oil under pressure to said gearing to lubricate said gearing, and to said fluid coupling to furnish working liquid thereto, and means built into said housings and controlled automatically by fluid conditions at the outlet of said compressor for automatically controlling the amount of oil in said coupling independently of said pump, whereby the slip in said coupling is regulated and the speed of said compressor is varied.

8. In a unitary supercharging assembly including a driven shaft housing, a drive shaft housing, and an intermediate shaft housing, a high speed centrifugal compressor mounted in the driven shaft housing, a step-up power transmission for said compressor including a fluid coupling and gearing in the intermediate shaft housing, means including a pump in the drive shaft housing for supplying oil under pressure to said gearing to lubricate it, and to said fluid coupling to supply working liquid thereto, and means controlled automatically by fluid conditions at the outlet of said compressor for removing oil from said coupling in varying amounts to produce slippage by which the output of said compressor is regulated.

9. In a unitary supercharging assembly including a driven shaft housing, a drive shaft housing, and an intermediate shaft housing, a high speed centrifugal compressor mounted in the driven shaft housing, a step-up power transmission for said compressor, including a fluid coupling and gearing in the intermediate shaft housing, means including a pump in the drive shaft housing for supplying oil under pressure to said gearing for lubrication, and to said fluid coupling as a working liquid, said means including a hollow post formed integrally with the intermediate shaft housing, and having discharge orifices adjacent units of said gearing, and means controlled automatically by fluid conditions at the outlet of said compressor for removing oil from said coupling in varying amounts to produce slippage for regulating the output of said compressor.

10. In combination, a high speed centrifugal compressor, a drive shaft, a power transmission between said drive shaft and said compressor, including a fluid coupling and a transmission gearing, a pump driven from said drive shaft for supplying motive oil to the working chamber of said coupling, and to said gearing to lubricate said gearing, and means for controlling the amount of motive liquid in said coupling automatically according to fluid conditions at the outlet of said compressor to vary the output speed of said compressor.

11. In combination, a high speed centrifugal compressor including an impeller, a shaft for said impeller and bearings for said shaft, a drive

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shaft, a power transmission between said drive shaft and said impeller shaft including a fluid coupling, a pump driven from said drive shaft for continuously supplying motive oil to the working chamber of said coupling, conduit means leading from the outlet of said pump for delivering oil to said bearings to lubricate said bearings, and means automatically controlled by fluid conditions at the outlet of said compressor for regulating the amount of liquid in said coupling independently of said pump to vary the slip in said coupling, and thereby vary the speed of said compressor.

12. In combination, a high speed centrifugal compressor including an impeller, a shaft for said impeller and a pair of spaced bearings for said shaft, a drive shaft, a power transmission between said drive shaft and said impeller shaft, including a fluid coupling and a transmission gearing, a pump driven from said drive shaft for supplying motive oil to the working chamber of said coupling, conduit means leading from the outlet of said pump for delivering lubricating oil to said transmission gearing and to said shaft bearings to lubricate said gearing and said bearings, and means automatically controlled by the pressure at the outlet of said compressor for regulating the amount of liquid in said coupling independently of said pump to vary the slip in said coupling, and thereby vary the speed of said compressor.

13. In combination, a high speed centrifugal compressor including an impeller, a shaft for said impeller and bearings for said shaft, a drive shaft, a power transmission between said drive shaft and said impeller shaft including a fluid coupling and a transmission gearing, a pump driven from said drive shaft for continuously supplying motive oil to the working chamber of

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said coupling, means leading from the outlet of said pump for delivering oil to said bearings and to said gearing to lubricate said bearings and said gearing, an adjustable scoop for transferring motive oil from said coupling, said scoop being in the form of an arcuate tube having its discharge end pivotally mounted adjacent, but to one side of the center of the coupling, whereby its inlet end is movable from a position adjacent the periphery of the coupling to a position adjacent the center thereof, and means automatically operable in accordance with the pressure at the outlet of said compressor for operating said scoop about its pivotal support.

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