The pump used to circulate fluid for thermal control in an astronaut's space suit for the moon landing program is being investigated for use in an extracorporeal heart or in an implantable artificial heart-lung system.

Several adverse physiologic effects occur in prolonged pumping of blood with an artificial. These problems include hemolysis (the release of hemoglobin from red blood cells), "ghosts" (envelopes left over after red blood cells disrupt), anemia (decreased number of viable red blood cells), increased viscosity, protein denaturation (albumin destruction), increased plasma turbidity, lipemia, and platelet abnormalities (thromboembolism and shortened survival of platelets) (1,2,3).

Different kinds of pumps that have been tested for use in heart-lung systems include the roller pump (4), the diaphragm pump (5), the ventricle pump (6), the Impeller pump (7), the rotor pump, and the cam-driven plunger pump. The amount of hemolysis is the criterion most often used to evaluate heart pumps. Although there are other physiologic consequences of pumping (discussed above) we have limited the evaluation of our pump in terms of the amount of hemolysis rather than to the other physiologic factors described in the preceding paragraph.
PUMP DESIGN

The pump used in this study was developed for the Apollo program to circulate water for cooling purposes within the astronaut space suit ( ). Desirable features include low weight, small size, high efficiency, reliability, and DC power. This pump, a Whittaker double diaphragm (WDD), is a double-acting, positive displacement diaphragm type. As shown in Figure ___, two Dacron diaphragms, coated with butyl rubber, are attached at the end of an oscillating beam mounted on a torsion bar. Each diaphragm covers a chamber equipped with inlet and outlet check valves.

While one diaphragm is pressurizing its chamber, thereby opening the outlet valve, the other diaphragm is providing suction to the alternate chamber. When the oscillating beam is moving in the opposite direction, each chamber reverses its function. The resulting two pulsatile streams are combined to produce a nearly continuous flow.

The pump "motor" is unconventional. Part of the oscillating beam is the armature for a two-position solenoid. The solenoid is operated magnetically by an integrated electronic control circuit at the natural frequency of the oscillating beam resulting in high efficiency. The "motor" and electronics, in a separate compartment, have the advantages of being apart (isolated?) from the blood being pumped, thereby preventing corrosion and bearing contamination.

TEST PROCEDURE

Hemolytic Index (HI)

Hemolytic index (HI) used for over 15 years is defined as the amount of hemoglobin in milligrams released into the
plasma in pumping 100 ml of blood. The formula for HI is

\[ HI = \frac{(100-Hct) \times C}{100} \times \frac{V}{Q \times t} \]

where

- \( C \) = increase in plasma hemoglobin concentration in milligrams per 100 ml plasma during a test time \( t \) (in minutes)
- \( V \) = volume of total circulating blood
- \( Q \) = quantity of blood pumped in milliliters per minute
- \( Hct \) = hematocrit

Issue has been taken with the use of HI to evaluate hemolysis with pumps (8). Although other criteria have been proposed to determine hemolysis, we used HI as do most investigators, because it provided the most widely applied standard of comparison.

Test System

The procedure used to determine the HI of pumps (heart-lung?) is standardized (9). Six feet of closed loop Tygon tubing (3/8 inch inner diameter and 1/2 inch outer diameter) were connected between the output and input of the pump. This tubing was wrapped as a helix with the top of the helix being 60 cm above the base of the pump (Fig. ). All studies were done at room temperature on canine blood with a hematocrit of more than 35%. The pump system was thoroughly washed with water at the end of each experiment.

Blood was introduced into the test system until no air remained in the pump chambers or tubing. After three minutes of pumping in the test system to permit mixing, a control plasma hemoglobin and hematocrit sample was drawn with the pump running. The time at which the sample was taken was
designated as time zero. The increase in plasma hemoglobin, $C$, was measured with respect to this zero time.

Plasma hemoglobin was determined as follows:

1. withdraw 5cc of blood into a tube containing ____ of heparin
2. centrifuge for 5 minutes
3. pipette 1 cc of plasma into 5cc Drobkins (?) solution
4. let stand 10 minutes
5. place in hemophotometer (Fisher Flo-Thru model) ??
6. divide hemophotometer reading by 50, with results reading in Gm%.

(Next paragraph deleted for use in other part of manuscript)

Test Results With WDD Pump

Using canine blood at room temperature (with the previously described test procedure) the WDD pump had a HI = .0015 at 60 minutes. Thus, prior to a recent report by Bernstein (10), our pump has a HI that is almost 100 times less than previously reported pumps. A series of runs from the WDD pump are shown in Figures (Tables???) ____ through ____; the HI as a function of time, corresponding to these runs, is shown in Figure (Table??) ____.