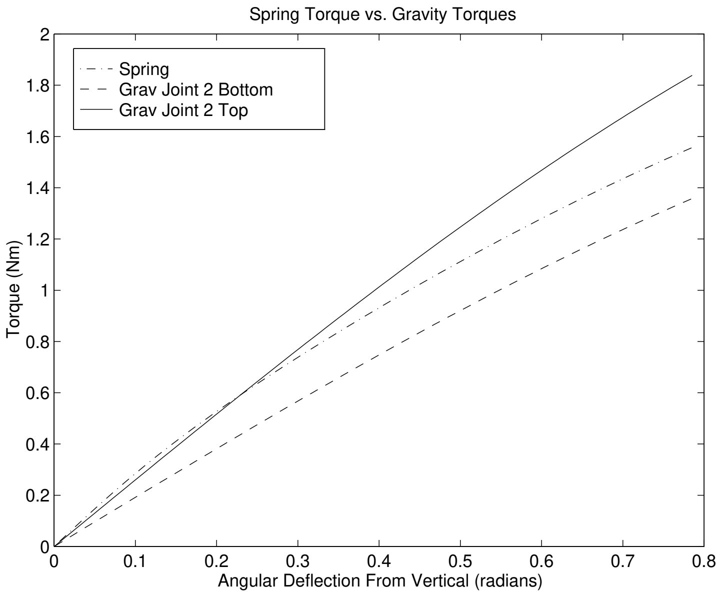

Figure 5-8: The spring counterbalance approximately balances gravity torques due to imbalance. Gravity torques are shown with the joint 2 axis in its bottom and top positions

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5.2.2 Wrist Unit

We now begin a detailed desription of the wrist unit. Recall that the main goals of the wrist unit are: (a) to provide extra degrees of freedom within the body, distal of the incision point, for dexterity and (b) for these freedoms to be low in inertia and to have low friction to allow macro-micro control to be implemented.

Figure 5-9 shows the five DOF wrist unit. The wrist unit, 12, consists of two sections, a distal portion, 28b, which is connected via a rotary joint, 26, to a proximal portion, 28a. The distal portion consists of two fingers and a wrist, mounted on an instrument shaft through which cables pass to actuate the wrist and fingers.

The proximal portion consists of a linear sliding joint, 30, which allows the instrument to pass into and out of the body, and appropriate pulleys to terminate the cables which actuate the wrist and gripper. Five actuators, M2, M3, M4, M5, and M6 are used to power and control these freedoms and are rigidly face mounted to a bracket, 96, which in turn mounts to the base positioner.

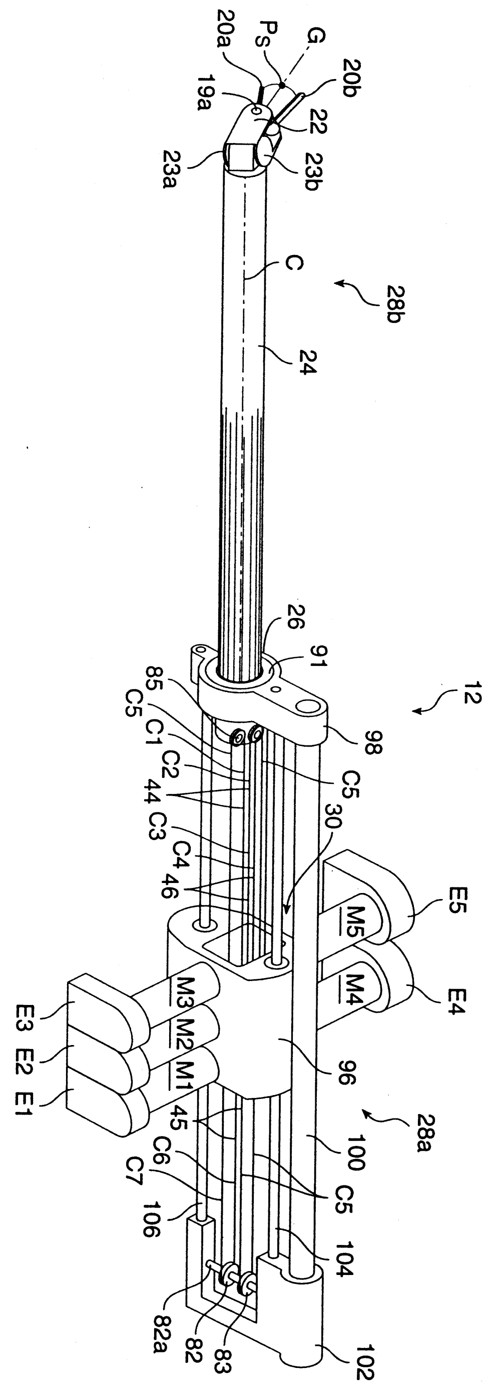

Figure 5-9: The wrist unit for the Silver Falcon has five degrees of freedom: translation in the direction of the instrument shaft, rotation about the instrument shaft, wrist pitch, and individual rotation of each finger.

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5.2.2.1 Wrist Kinematics

Description of the roll-pitch-yaw kinematics with offset axis and grip lying on the same axis as the distal yaw axis.

5.2.2.2 Distal Portion

Lets look more closely at the distal portion, 28b, which includes the wrist, gripper, and instrument shaft. In order to more clearly describe the cabling scheme, I will first describe a simplified version of the wrist and gripper shown in Figure 5-10. The actual version used in the Silver Falcon is described in Section 5.2.2.5 below. The two versions are in fact similar, though for reasons we will explain, the actual version used has substantially less friction than the version described below. The cabling scheme will be described in Section 5.2.2.4.

Referring to Figure 5-10, the wrist is mounted to a hollow aluminum instrument shaft, 24, mounted along axis C, through which four cables, C1, C2, C3, and C4 pass. The tongue, 24a is mounted to the wrist tube and supports a steel shaft in small ball bearings. The wrist member, 22, pivots on this shaft about axis B which is orthogonal to axis C. Two fingers, 20a and 20b, are attached to driven capstans, 18a and 18b, respectively. Each of these fingers operates independently. The fingers and driven capstans are in fact each machined from single pieces of stainless steel. The wrist member, 22, suports a steel shafts at axis A which in turn supports the driven capstans. Intermediate idler pulleys 70, 72, 74, and 76 lie along the shaft of axis B. Two small ball bearings are mounted in each driven capstan, and one in each idler pulley to minimize friction.

It is important to note that in this wrist the smallest pulleys are the intermediate idler pulleys, 70, 72, 74, and 76 which are roughly half the diameter of the shaft. One of the main objectives in designing a wrist is to keep the diameter of pulleys within the wrist as large as possible, where the upper limit will be the diameter of the instrument shaft. There are two reasons for this. First, steel cable has a minimum bending radius about which it may turn since repeated bending stresses in the cable will cause fatigue and failure in the individual cable fibers. This is well documented in cable catalogs and limits are given for pulley radius for given cable diamters of given constructions. For a small number of cycles, however, actually breaking the cable due to fatigue may not be an issue. The second reason is that there may be substantial friction caused by pulling cable over a small radius. The motion of cable fibers relative to each other increases as the pulley diameter decreases, while at the same time cable tension is distributed over a smaller area. Under load this internal rubbing of the individual cable fibers represents energy loss and manifests itself as

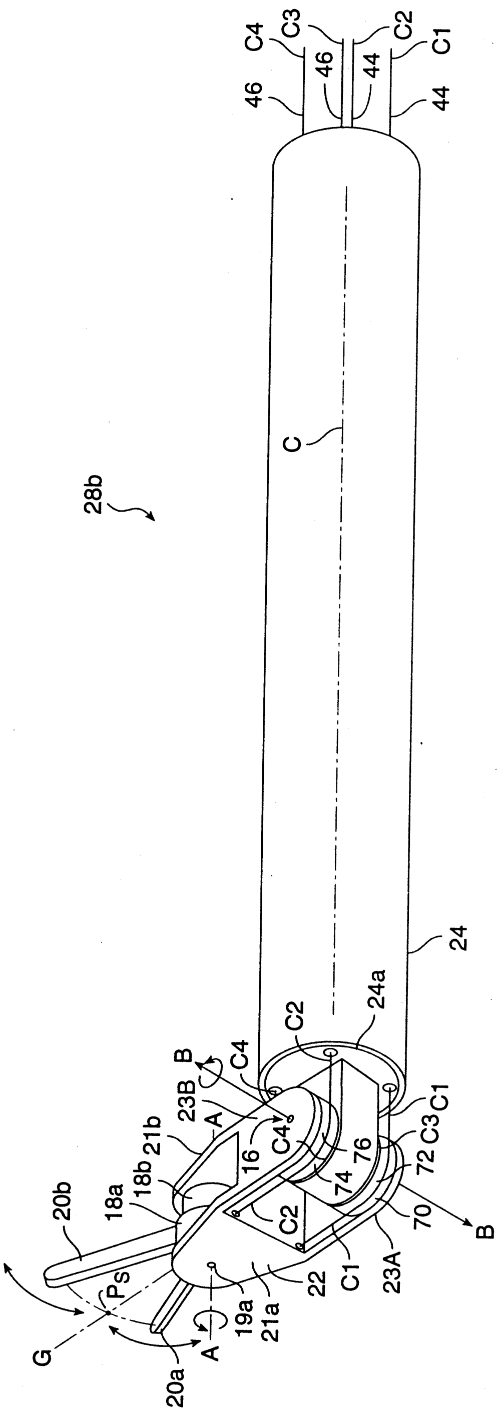

Figure 5-10: This is a simplified version of the silver falcon wrist used to describe the cabling concept.

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