PROGRESS REPORT

(HC) $1.00
(MF) .50

1 September 1966

National Aeronautics and Space Administration Grant: 05-004-008

With: The University of California (Davis Campus);

Entitled: "CHRONIC ACCELERATION STUDIES -- PHYSIOLOGICAL RESPONSES TO ARTIFICIAL ALTERATIONS IN WEIGHT."

Co-principal Investigators: C. F. Kelly, Professor of Engineering
A. H. Smith, Professor of Physiology

Principal Collaborators: E. L. Besch, Assistant Research Physiologist
R. R. Burton, Associate Specialist (Pathology)
S. J. Sluka, Associate Specialist (Engineering)

INFLUENCE OF THE AMBIENT ACCELERATIVE FORCE ON FEED INTAKE

Comparative studies over the past century have established an exponential relationship between body size and metabolism -- as well as between body size and many other physiological and anatomic parameters. Reviews and historical accounts of these classic concepts are contained in the books by Brody (1945) and Kleiber (1961). These relationships between size and metabolism generally have been referred to some derivative of body weight -- which, by definition, is equivalent to body mass under the condition of Earth-gravity. However, weight is not a fundamental property of matter, but merely a phenomenon developed in a restrained body exposed to an accelerative force:

$$W = M \times \frac{a}{g}$$

Where: "W" and "M" represent weight and mass in equivalent units (i.e., lbs., kg., etc.); and, "a" is the ambient accelerative force, in the same units as "g", the Earth's gravitational constant (i.e., 980 dynes, 32 ft./sec.^{2}, etc.).

The dynamic properties of an environment are described by the W:M ratio (conventionally designated as "G:" see: Dixon and Patterson, 1953; and, Human Acceleration Studies, 1961). It also is evident from the above equation that a body of a certain mass may exhibit a different weight, when exposed to a force other than Earth-gravity.

With the development of astronautics, prolonged alteration of the W:M ratio of man, as well as other organisms, has become a reality. Changes in metabolic function (including the maintenance feed requirement) may be anticipated from such "artificial changes in weight." For example, the work required for moving a body against an accelerative force is a function of its weight, rather than its mass, as indicated by the equation for potential energy:

$$P.E. = h \times M \times \frac{a}{g} = h \times W$$

Where: "h" is the distance of movement; and, other symbols have the same significance indicated previously.

Consequently, in a hyperdynamic ("super-gravity") environment, a greater work requirement may be anticipated for equivalent tonus, locomotion, circulation, etc., and this must be met by an increased energy metabolism.

Over the past fifteen years, several programs have been developed to examine various aspects of biological changes resulting from the chronic exposure of animals to fields of greater strength than Earth-gravity. Others have been reported by: Matthews, 1953; Wunder, et al., 1963; Oyama and Platt, 1965; and Lang et al., 1965. One of our interests is the influence of chronic-acceleration on energy metabolism, as indicated by the maintenance feed requirement, and the results of these investigations are reported herein.

METHODS

On Earth, studies of the effects of prolonged alteration of the dynamic property of the environment necessarily deal only with increases, since no way is known to limit the force of gravitation. Also such studies must depend upon centrifugal forces, since even moderate linear accelerations would place an exposed object in Earth-orbit in a matter of minutes. Unfortunately, in addition of producing an accelerative force, centrifugation also involves turning -- which has distinct biological effects. This can be reduced, but not eliminated, by lengthening the centrifuge's radius of rotation. However, the influence of turning upon observed phenomena can be tested separately. Since the centrifugal force is proportional to the square of the rotation rate (at a particular radius), it is possible to expose animals to a fairly rapid turning (e.g., 5-10 rpm) without developing a significant increase in the accelerative force. Under such conditions, no differences are evident between "rotated" and control animals. Other studies (Winget, et al., 1962) have indicated no great change in labyrinthine function as a result of chronic acceleration at much greater rates of rotation (e.g., 30 rpm). From such observations, we conclude that the predominant factor in the centrifuge environment is the increased accelerative force. Also, from Einstein's "principle of equivalence" it is generally considered that the effects of accelerative forces produced by motion are the same as those produced by gravitation.

The contructional details of the instrument used in some earlier experiments, as well as the operating characteristics of animal centrifuges generally, have been communicated previously (Kelly et al., 1960). The experiments reported herein were done on a larger (18' diameter) centrifuge, which has only been partially described elsewhere (Smith & Kelly, 1965; Wunder, 1965). The acceleration schedule for these experiments is described in Figure 1. During an experiment the centrifuges are stopped for a few minutes each day to permit feeding and a brief examination of the birds (e.g., so that "sick" birds could be eliminated). Weekly, the centrifuges are stopped for a longer time (perhaps 1-2 hours), to permit cleaning cages, determination of body mass, etc. Thus, the indicated treatment prevailed about 98% of the time.

All experiments were conducted on adult Leghorn (SCWL) chickens, from an "acceleration tolerant" strain developed by serially reproducing survivors of chronic acceleration experiments (Smith and Kelly, 1961; Burton and Smith, 1965). These animals differ from unselected strains principally by exhibit-

RESULTS

The *ad libitum* feed intake, and associated changes in body mass (both as gms/kg body mass/day) for each observation period of control and centrifuging animals are presented in Table 1. An examination of these data reveals rather substantial variations in feed intake, even for the same group between observation periods. Some of this variability is technical or related to changes in the environment. Consequently the feed intake and other measurements were pooled for several periods, where the observations were completed within 30-40 days, and this reduced the variability. Such data are presented for feed intake and metabolizability in Table 2, and for mean body mass and change in body mass in Table 3. Only data obtained more than 30 days after the last groups (i.e., 5, 6, 9 and 10, Figure 1) were placed on the centrifuge are included. At this time, no marked differences in results are evident between groups that had been centrifuging for 30 days, and those centrifuging for 130 days.

In the data presented in Tables 2 and 3, variation in feed intake accompanied by similar changes in body mass. Consequently, a linear regression of changes in body mass upon feed intake was made, using data from individual periods over the 6 months covered by periods "i" to "r" (Table 1), and the results of this analysis are presented in Table 4. From these it is evident that as the ambient accelerative force increases (from normal gravity to 2G), the feed requirement for maintenance increases, and the change in body mass per gm feed (i.e., the slope of the regression) also increases. This latter result correlates with the greater rate of loss of body substance by centrifuging animals during 3 day fasts (which were interspersed between the feed intake trials):

	(n)	Fasting loss rate (gm/kg body mass/day)	Recovery rate (gm/kg body mass/day)
Normal gravity	14	26.1 ± 1.3*	25.0 ± 2.1*
1.5 G	18	33.9 ± 1.2	35.7 ± 1.5
2.0 G	20	38.8 ± 1.1	39.1 ± 1.0

* mean and standard error

This greater change in body mass, relative to change in feed intake, of centrifuging birds indicates a lesser energy content of their tissues. This also is evident in the lesser body fat of centrifuging birds (Smith & Kelly, 1963), which appears to be a general response, being observed in centrifuged rats as well (Casey, 1965). Several groups (1, 5 and 10) were sacrificed at the end of the centirfugation period, and the dressed carcasses analyzed for fat content:

Composition of carcas soft tissue

	fat (%)	water (%)	feed equivalent per gm tissue*
gravity	8.17±1.06	69.23 ± 2.03**	5.17 gm
1.5G	5.20±0.63	70.12 ± 0.42	4.16 gm
2.0G	4.40±0.63	72.07 ± 0.71	2.08 gm

* reciprocals of slopes of regressions, Table 4

** mean and standard error