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Powered wheelchair bucking

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Abstract—Using a dummy test driver with a simulated flaccid forearm capable of representing either a large or zero friction condition, six powered wheelchairs were examined for bucking tendencies. In the zero friction condition, bucking was easily induced in 5 of 6 tested wheelchairs. Adding friction to the simulated forearm prevented bucking in all tested wheelchairs but one. Bucking is not simply related to wheelchair performance measures such as speed or acceleration. Sustained bucking corresponds to neutral stability in a speed regulated machine. Changes in natural frequency and damping characteristics are predicted as useful in reducing powered wheelchair bucking.

INTRODUCTION

The bucking of power wheelchairs defines a specific control problem in which the vehicle jerks back and forth despite the efforts of the user to produce a smooth motion. While this problem is rare, clinical observations indicate that the combination of certain wheelchair users, driving certain models of wheelchairs, is likely to lead to bucking.

In many ways wheelchair bucking is similar to the process observed when unskilled drivers attempt to accelerate automobiles equipped with mechanical clutches. In either case, the vehicle executes a violent oscillation superimposed upon a basic trajectory. With experience, the typical automobile driver develops skills necessary to dampen the unwanted oscillation. However, in the case of wheelchair users, those with impaired upper extremity function can find it difficult and even impossible to master the appropriate skills. It would appear desirable to design power wheelchairs so as to preclude bucking.

A useful first step in such a process is to establish the root cause of bucking. In this work the physical characteristics of a known bucking wheelchair are compared to those of five power wheelchairs selected at random. At issue is the pertinence of such mechanical design factors as acceleration, jerk, top speed, etc., to bucking.

METHODS AND MATERIALS

A group of six power wheelchairs were examined for bucking tendencies and the results compared with physical measures of acceleration, jerk, and top speed. The one wheelchair found to possess unacceptably poor bucking characteristics, and never put into production, will be termed the "X" wheelchair. Other tested machines include the E&J–3P, E&J–3N, Vessa Std, Insta-Gaiter, and an in-house development termed "Pancake."

The physical characteristics tests employed in this work are those described in the 1979 *Veterans Administration Standards for Electrically Powered Wheelchairs*. To measure acceleration and jerk, a male driver clasped a commercial servo accelerometer to his breastbone, using both hands to assure firm and level positioning of the sensor. From a standing start, an assistant standing to one side of

the wheelchair moved the control stick as rapidly as possible. The results were displayed on a conventional oscilloscope and photographed for subsequent analysis (**Figure 1**). At least 6 runs were averaged in arriving at final results. The maximum amplitude of the acceleration versus time curve was taken as the peak acceleration value and is given relative to the acceleration of gravity. Thus, 0.4 g means an acceleration equal to 40 percent that of gravity.

Jerk was determined by graphically differentiating the acceleration versus time records in the conventional manner, i.e., slopes were measured and converted. Units are based on changes of gravitational acceleration per unit time; a jerk rating of 2 g/sec means a jerk equivalent to a change twice that of gravitational acceleration occurring in one second.

Velocity was determined by stop watch time measurements over a known traverse.

Bucking tests were conducted with an anthropomorphic dummy (175 lb) serving as "driver". Two types of forearm restraint were simulated (**Figure 2**). A 5 lb. metal bar, serving as the forearm and hand, was connected to the control stick through a slopfree low friction, nylon ball pivot. The "elbow" end of the bar was either supported by rubber bands, to produce a free floating, undamped support suggesting a flaccid forearm (upper sketch); or the "elbow" was arranged to create considerable mechanical friction upon motion (lower sketch). The latter case was considered equivalent to a highly damped forearm.

To initiate a bucking trial, the simulated arm was moved at maximum acceleration by the operator and then released. Observations were made of the persistence of any motion oscillation following release. If all subsequent oscillations stopped within two oscillation periods, the bucking trial was rated "NO". If oscillations persisted for more than two periods, the trial was rated "YES".

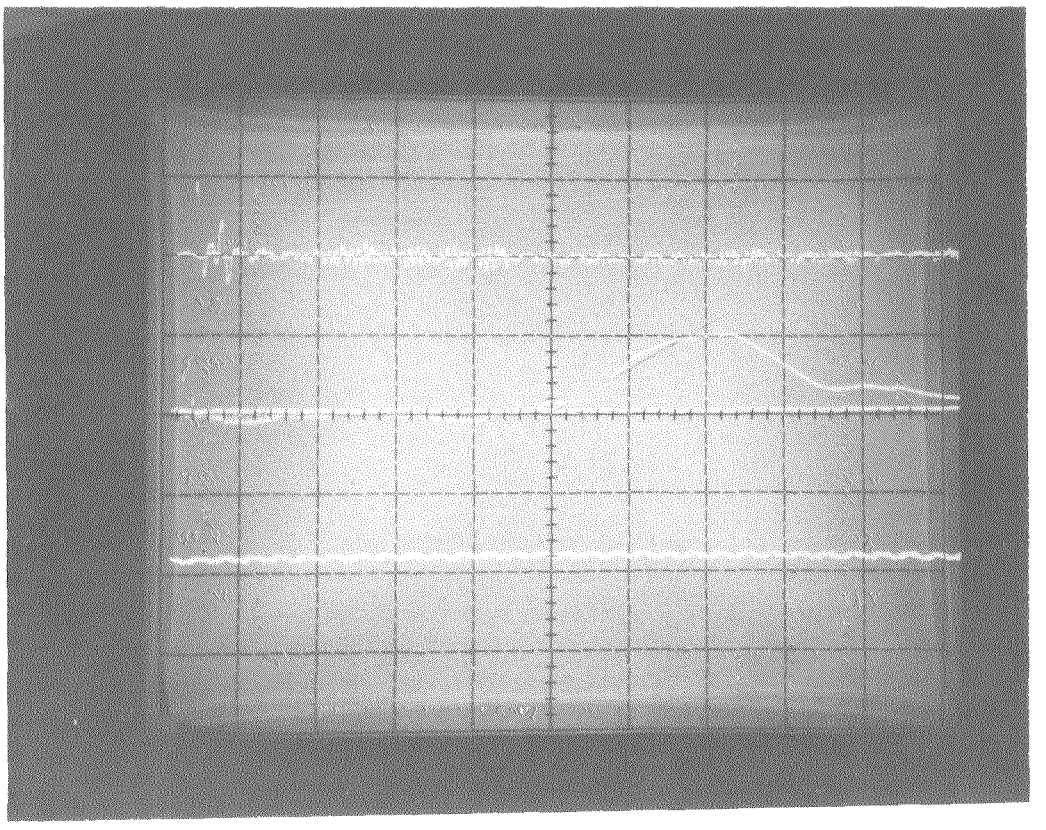
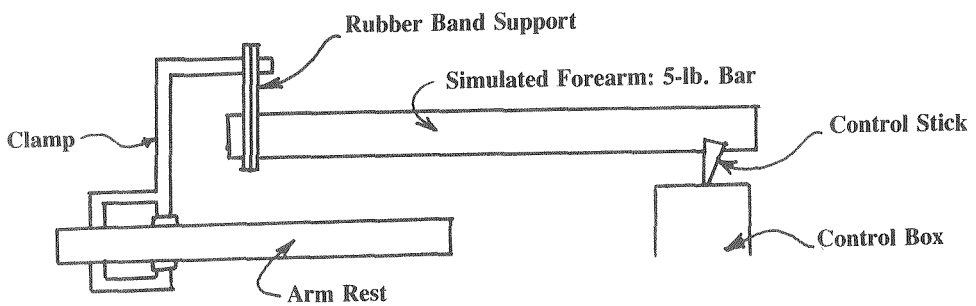
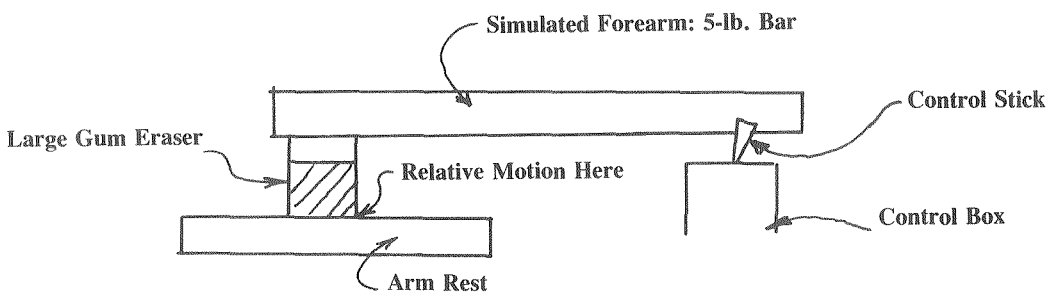


Figure 1.
Typical acceleration test data. Upper and lower horizontal lines are calibration runs at +1 g and –1 g, respectively. The maximum acceleration run starts near origin on horizontal (time) axis and proceeds to right. Time axis units are 0.05 seconds per box. Vertical ordinate (acceleration) units are roughly 0.5 g per box. Wheelchair under test was the Vessa Std.



SIMULATED FLACCID FOREARM: SIDE VIEW



SIMULATED DAMPED FOREARM: SIDE VIEW

Figure 2.
Model forearm restraint systems as employed in bucking tests.

RESULTS

All measured wheelchair physical and bucking characteristics are given in **Table 1.** The Pancake and X devices represent the extremes of the bucking range; the Pancake could not be induced to buck, while the X chair bucked in all tested circumstances. Once bucking was initiated, the X chair continued to buck without limit, slowly moving into a circular trajectory. The acceleration versus time characteristics of the X chair, taken in sustained bucking, are given in **Figure 3.**

The remaining vehicles have moderate and roughly equal bucking tendencies. Each can be induced to buck in the flaccid forearm condition, yet each resists bucking in the damped forearm condition.

Our concern is with the root cause of bucking and specifically with possible associations between

Table 1
Wheelchair Bucking and Physical Characteristics

Wheelchair	Physical Characteristics				Sustained Bucking?	
Mfg Design	Control Type	Max Vel MPH	Peak Accel (g)	Jerk g/sec	Flaccid Forearm	Damped Forearm
E&J-3P	Prop	4.2	.42	6.6	YES	NO
E&J-3N	Micro	3.1	.36	6.9	YES	NO
X	Micro	2.5	.41	5.1	YES	YES
Vessa Std	Prop	1.7	.47	4.1	YES	NO
Insta-Gaiter	Prop	2.7	.38	5.6	YES	NO
Pancake	Micro	NA	.15	1.6	NO	NO

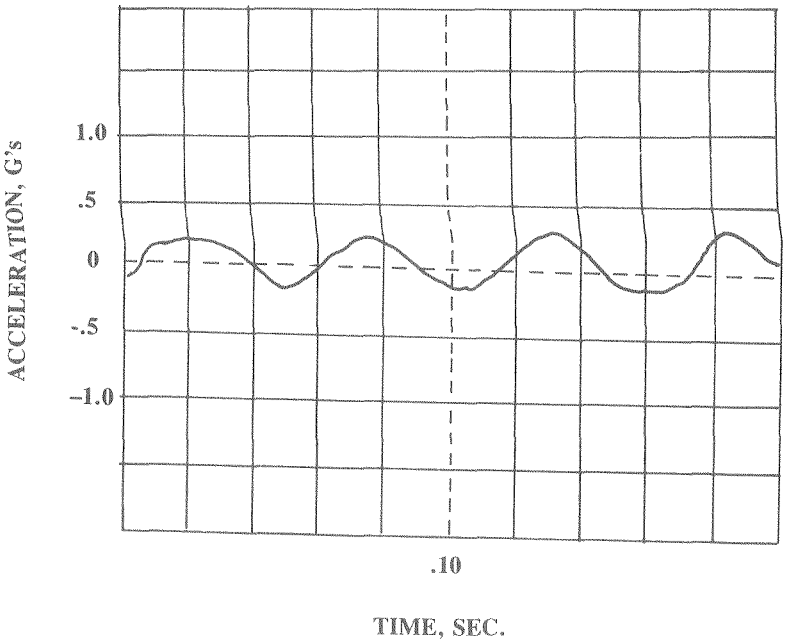


Figure 3.
Sustained bucking oscillation. The accelerometer is clasped to the "breastbone" of the 175-pound dummy driver seated in Wheelchair X. The bucking frequency is roughly 3 cycles per second; acceleration amplitude roughly ± ¼ g.

bucking and wheelchair physical characteristics. Examination of **Table 1** does not produce a clear association. Both the X chair and the Pancake have microswitch controls; as noted previously, the X bucks readily and the Pancake not at all. The acceleration and jerk characteristics of the Pancake are the lowest of all, implying some possible relationship of bucking to acceleration; and yet the X chair acceleration values are mid-range and unexceptional.

DISCUSSION

Bucking may be viewed as a process similar in nature to that of governor hunting. Within this analogy, the control box plus the operating hand is viewed as a governor, always attempting to oppose wheelchair acceleration by applying a reversing force. Thus the system is viewed as always possessing static stability.

For example, a forward acceleration of the wheelchair tends to cause the driver's arm to lag the motion, owing to the arm's intertia. The lag is sensed at the controller as a rearwards motion, acting to either diminish the forward acceleration or perhaps to produce a rearwards acceleration. Such a system, always acting in opposition to the basic wheelchair acceleration, is inherently stable in the sense that a restoring force accompanies any departure from constant velocity.

While this form of static stability has a basically stabilizing tendency, it is possible for a situation to arise where repeated sign changes at an ever growing amplitude (dynamically unstable) or where the amplitude of endlessly reversing changes in acceleration becomes constant dynamically (neutrally stable) rather than diminishing and finally vanishing (dynamically stable).

Observations of bucking data (**Figure 3**) suggest that of these various possibilities, the case of neutral dynamic stability accompanying great static stability describes that undesired bucking condition most likely to occur in practice. To examine this condition, we shall consider the classic governor analogy in some detail, using expressions describing the self-excited or hunting vibrations of such a system.

The force relationship describing this situation has been given (1) as the following:

$$m\ddot{x} + d_c\dot{x} + k_c x = c_1\dot{\varphi} \qquad [1]$$

$$I\ddot{\varphi} + d_w\dot{\varphi} + k_w\varphi = -c_2 x \qquad [2]$$

where x = displacement of the control lever from a constant velocity position;
m = equivalent mass of that suspended portion of the driver's arm engaging the control stick;
d_c = damping coefficient of an assumed viscous damper placed within the control box;
k_c = stiffness of the control box spring;
c_1 = incremental change of control stick force caused by an incremental change in wheelchair motor speed of one radian per second;
$\dot{\varphi}$ = difference between instantaneous wheelchair drive motor speed and the normal or average speed at a given load;
k_w = stiffness of the wheelchair drive motor;
I = moment of inertia of all rotating parts;
c_2 = incremental change of wheelchair motor torque cause by incremental change of control stick;
d_w = damping coefficient of an assumed viscous damper placed within the wheelchair drive motor.

The solution, consistent with positive dynamic stability, has been given (1) as:

$$\left(\frac{d_w}{I}+\frac{d_c}{m}\right)\cdot\left(\frac{k_w}{I}+\frac{k_c}{m}+\frac{d_c d_w}{Im}\right)\left(\frac{d_c k_w}{Im}+\frac{d_w k_c}{Im}+\frac{c_1 c_2}{Im}\right)>\left(\frac{d_c k_w}{Im}+\frac{d_w k_c}{Im}+\frac{c_1 c_2}{Im}\right)^2+\frac{k_w k_c}{Im}\left(\frac{d_w}{I}+\frac{d_c}{m}\right)^2 \qquad [3]$$

The above expression includes too many factors to permit simple assessment; it is instructive to note that the controller damping factor $\frac{d_c}{m}$, the wheelchair motor damping factor $\frac{d_w}{I}$, the natural frequencies $\sqrt{\frac{k_c}{m}}$, $\sqrt{\frac{k_w}{I}}$ and the coupling factor $\frac{c_1 c_2}{Im}$ are all pertinent to the issue of stability.

One simple conclusion that can be drawn from Equation [3] is that in the absence of damping $d_c = d_w = 0$, the left hand side goes to zero, while the right side is positive. It follows that in the absence of all damping, dynamic stability is impossible.

Next consider the case where motor damping is zero. Then Equation [3] reduces to:

$$\frac{d_c I(k_c/m - k_w/I)}{c_1 c_2} > 1 \qquad [4]$$

Here, should the control box frequency be less than the motor frequency, the left side is necessarily negative and dynamic instability impossible, even if the control box is heavily damped. Conversely, when the control box frequency is greater than the motor frequency, the left hand side is positive and stable operation follows if the control box damping is larger than:

$$d_c > \frac{c_1 c_2}{I(k_c/m - k_w/I)} \qquad [5]$$

Finally, in the case where the motor is considered damped but the control is taken as without damping, Equation [3] reduces to:

$$\frac{c_w m}{c_1 c_2}(k_w/I - k_c/m) > 1 \qquad [6]$$

which implies instability if the controller frequency is greater than the motor frequency.

In applying these results, the designer or technician usually has but a limited choice concerning motor characteristics. However, most controllers are capable of spring modification so as to increase stiffness or natural frequency. Controller damping may be altered by changing armrest position or upholstery so as to vary the portion of arm load carried by the armrest or the coefficient of friction experienced when contacting the armrest. In extreme cases where the upper arm is entirely flaccid, it might be useful to restructure the armrest in order to accept as much forearm frictional load as possible.

The practical effect of forearm damping is great. As given in **Table 1**, simulated frictional forearm damping proved sufficient to prevent sustained bucking in 5 out of 6 tested wheelchairs.

As concerns bucking analysis, it has been predicted that increases in controller frequency and damping should be capable of providing dynamic stability in certain otherwise unstable cases. Specifically, in instability, one should increase controller

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damping in the event that controller frequency is greater than the motor frequency.

Finally, the possibility of attaching a dashpot to the control stick should be noted. One can easily imagine a grease-filled chamber serving as a means of preventing bucking even for those wheelchair users with flaccid forearms.

In summary, bucking, easily induced in 5 of 6 tested power wheelchairs, is viewed as a form of dynamic instability, controllable through appropriate damping measures.

CONCLUSIONS

1) Bucking could be easily induced in 5 of 6 powered wheelchairs through use of a simulated flaccid forearm. For those with an impaired upper extremity function, these results suggest that bucking constitutes a practical problem

2) Bucking is not simply related to such wheelchair performance measures as top speed, maximum acceleration or jerk. Microswitch control is not, of itself, a sufficient pre-condition for bucking.

3) Bucking may be viewed as a form of dynamic instability superimposed on a machine possessing a strongly positive static stability.

4) Analysis suggests that proper design of control box and motor frequencies, in addition to certain damping regulation measures, can contain bucking.

5) Practical experiments with simulated forearm damping indicate reasonable levels of damping act to prevent bucking in 4 of 5 tested wheelchairs. Only 1 of the original test group of 6 wheelchairs could not be adequately restrained from bucking, when given adequate forearm damping.

REFERENCES

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2. *Veterans Administration Standards for Electrically Powered Wheelchairs*. Reproduced in *Bull Prosthet Res*, Spring 1982 19(1):130–138, 1982. Test procedure actually followed an earlier (1979) version of "Standards" (unpublished). Certain details of technique differ in the two versions.