BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D.C. 20024

B70 11055

SUBJECT: A General Discussion of Crew Safety Traverse Constraints Case 320

DATE: November 25, 1970

FROM: P. Benjamin

ABSTRACT

An attempt is made to discuss and clarify the general case, without introducing specific values, of the form, application, and interpretation of the crew safety constraints which limit lunar surface traverses. The emergency return groundrules which underly these constraints require provision for safe return to the LM by walking in case of an LRV failure or by riding, using the B/SLSS, in case of a PLSS failure.

The format for presenting these constraints graphically is a plot of maximum return distance to the LM against elapsed time in the EVA. An envelope, within which the traverses must be designed, is defined by the fixed OPS flow time available for a riding return to the LM early in the EVA, and by the declining PLSS consumables available to support a walking or riding return late in the EVA. Equations are developed to describe the declining return distance available as the consumables are reduced, and the sensitivity of the limit lines so defined to modifications of the parameter values is described.

Provision of sufficient station time to perform comprehensive scientific exploration of the area and the EVA time limitations imposed by the total consumables available for the nominal traverse cause most traverses to fall well within the emergency return constraints. For those which do not, definition of the maximum return distance using a ratio of riding time to station time which corresponds to the traverses planned to date permits preliminary determination of walkback and rideback limits

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MEMORANDUM FOR FILE

INTRODUCTION

Recent discussions and presentations have revealed some uncertainties associated with the form, application, and interpretation of the crew safety constraints which limit lunar surface traverses. It has not always been fully understood which operational limits result from which constraints, groundrules, and hardware capabilities, and what the implications of these limits are. Further, the effect of variations in the parameters which define these limits has not always been clear. At least a portion of the current confusion is a result of the different formats which have been used to portray these constraints and the changing assumptions which have been used to define the limits, with consequent perplexity in interpretation of the limits portrayed in the various formats. An attempt is made here to discuss and clarify the general case, without introducing specific values, and one format is used. Hopefully this will explain the basic functional relationships of the traverse constraints.

Traverse design emergency return constraints originate in two groundrules:

1. Sufficient consumables shall be available in each PLSS at all times to allow the astronauts to walk back to the LM from a completely failed LRV.

2. Sufficient consumables shall be available in each PLSS at all times to allow both astronauts to ride back to the LM using the B/SLSS and consumables from one PLSS after complete failure of the other PLSS.

Partial failures of either the LRV or the PLSS are less restrictive than the full failure cases and are therefore generally not limiting. Total failure of both the LRV and a single PLSS or of both PLSS's is an unduly restrictive double failure, and is not considered.

TRAVERSE CONSTRAINT ENVELOPE

The format for presenting the constraints is shown in Figure 1. This figure plots maximum return distance (the maximum actual ground travel distance, not radius) against elapsed time in the EVA. This plot therefore shows at any given time in the EVA how far away from the LM the astronauts may be, and thus provides an envelope within which the traverses must be designed. This is the envelope which provides for crew safety in a nominal EVA. Once a failure actually occurs, it is assumed that the crew return immediately to the LM. Thus these envelopes have no significance after a failure has occurred.

In case of a PLSS failure the working and failed PLSS's are interconnected by the B/SLSS water hose and cooling water is supplied from the working PLSS to both astronauts. Oxygen is provided to the crewman with the working PLSS from his normal supply and the crewman with the failed PLSS obtains oxygen from his OPS, an oxygen storage tank of fixed capacity. The oxygen from the OPS flows at a predetermined rate and thus the maximum time available for return to the LM is determined by this flow rate and the tank capacity. This maximum time is constant during the entire EVA, and when multiplied by the assumed LRV emergency return velocity, defines the maximum distance from the LM to which the crew may go during the EVA. This constraint is depicted as a horizontal line in Figure 1.

As consumables are used during the EVA, less and less consumables are available to permit the astronauts to walk back from a failed LRV or to provide cooling for both crewmen during a riding return after a PLSS failure. At any time t this decreasing return capability may be written as

$$d_{RB} = \frac{v_{RB}}{\dot{C}_{RB}} C_{RE} \text{ for a riding return and}$$

$$d_{WB} = \frac{v_{WB}}{\dot{C}_{WB}} C_{RE} \text{ for a walking return, where}$$

d_{RB} is the maximum riding return distance at time t,

v_{RB} is the assumed LRV emergency return velocity,

$\dot{C}_{RB}$ is the rate at which consumables are used by two astronauts during an emergency riding return to the LM, and

C_{RE} is the amount of consumables remaining at time t after provision has been made for LM ingress and a fixed reserve.

The parameters are described analogously for the walking return except that $\dot{C}_{RB}$ refers to the water required to cool two men during the riding return and $\dot{C}_{WB}$ refers to all the consumables required to support one man during a walking return to the LM. This decreasing return distance capability resulting from the decrease of available consumables is depicted as a sloping line in Figure 1. The two lines shown define the traverse constraint envelope.

PARAMETER VARIATIONS

The quantity C_{RE}, the consumables remaining, is a nonlinear function of time, its variation depending upon the nature and duration of the activities carried out in the EVA. During the traverse, it may more accurately be represented as

$$C_{RE} = C_{TA} - \dot{C}_{TU}t \quad \text{where}$$

C_{TA} is the amount of consumables available for the traverse after provision for pretraverse activities at the LM, emergency LM ingress, and a fixed reserve, and

$\dot{C}_{TU}$ is the nonlinear rate at which consumables are actually used during the traverse.

Generally $\dot{C}_{TU}$ is simplified by considering only two fixed consumables usage rates - a high rate associated with activities at traverse stations, and a low rate for riding on the LRV. In order to observe the effect of variation in the parameters of the equations

$$d_{RB} = \frac{v_{RB}}{\dot{C}_{RB}}(C_{TA}-\dot{C}_{TU}t)$$

$$d_{WB} = \frac{v_{WB}}{\dot{C}_{WB}}(C_{TA}-\dot{C}_{TU}t)$$

it is convenient to assume a fixed ratio of riding time to station time during a traverse and to then approximate $\dot{C}_{TU}$ by a constant reflecting the proportionality of the two consumables usage rates.

Case 1: For given values of C_{TA} and $\dot{C}_{TU}$, it is possible to compare the effects of the rideback constraint, d_{RB}, and the walkback constraint, d_{WB}. Based upon presently agreed upon assumptions (References 1, 2, and 3) the consumables usage rate for two crewmen using the B/SLSS while riding on the LRV is about the same as the consumables usage rate for one man walking, or

$$\dot{C}_{RB} \approx \dot{C}_{WB} .$$

The LRV velocity during emergency return is assumed to be 3 times the walking velocity, or

$$v_{RB} = 3v_{WB} .$$

Thus

$$d_{RB} = \frac{3v_{WB}}{K_3}(K_1-K_2t)$$

and

$$d_{WB} = \frac{v_{WB}}{K_3}(K_1-K_2t) .$$

These are two linear equations with the same t intercept and slopes differing by a factor of 3, as is shown in Case 1 of Figure 2. It is apparent that the declining distance walkback constraint is always more limiting than the declining distance rideback except at the point

$$C_{TA} = \dot{C}_{TU}t$$

at which all the consumables have been used except those provided for emergency ingress and the fixed reserve. Since this point must fall considerably after the conclusion of a nominal traverse, it is of little more than academic interest. The OPS limited rideback constraint is, however, limiting in the early part of the EVA, as is shown in the figure.

Case 2: For a given v_{RB}, C_{TA}, and $\dot{C}_{TU}$ variations in $\dot{C}_{RB}$ illustrate the effects of various partial PLSS failures (i.e., the effects of varying consumables usage rates during emergency return). These changes correspond to alterations in the slope of d_{RB} but maintain the same t intercept, as is shown in Case 2 of Figure 2. The analogous effect occurs with d_{WB}. As is clear from Cases 1 and 2, variations of v_{WB} or v_{RB}, while all other parameters are held constant, have a similar effect. Thus as emergency return consumables usage rates or velocities vary, the slope of the limit line changes. Its intercept on the t axis is, however, fixed by the consumables available for the traverse and the nominal rate at which they are used.

Case 3: For a given v_{WB}, $\dot{C}_{WB}$, and $\dot{C}_{TU}$, variations in C_{TA} (increases or decreases in available consumables) change both the d and t intercepts by shifting the d_{WB} line to the right or left but maintaining its slope, as shown in Case 3 of Figure 2. The identical case holds for d_{RB}.

Case 4: For a given v_{WB}, $\dot{C}_{WB}$, and C_{TA}, various values of $\dot{C}_{TU}$ represent different linear approximations of the ratio of riding time to station time during the traverse. Variations in this ratio maintain the d intercept but vary the slope and the t intercept of d_{WB}, as illustrated in Case 4 of Figure 2. An identical result occurs for d_{RB}. Thus the latter portions of the traverse are more sensitive to the value of this assumed ratio than the earlier portions.

CURRENT USE

The format used here for presenting the traverse constraints is the one generally used by traverse planners at this time. The assumed values of velocities, consumables usage rates, and consumables available are defined for preliminary traverse planning purposes in Reference 3, soon to be published in final form. The actual values are expected to vary somewhat, but not greatly, from those in the reference. Variations in the assumed value of the riding time to station time ratio are still relatively large.

It is clear that one extreme case is that where there is no station time at all and the traverse is totally composed of riding. Since this results in the lowest possible consumables usage rate, it corresponds to the maximum return distance possible. That is, no traverse could be designed which would provide

any greater distance. The walkback distance line defined by a maximum riding traverse is shown in Figure 3, and all traverses will by definition be to the left of this line.

A corresponding minimum riding line can also be constructed. This line is defined by riding out radially from the LM any arbitrary distance, d, and then working at this traverse station until the decreasing distance walkback constraint forces a radial return toward the LM. Thus this line corresponds to linear radial traverses to arbitrary distances, d, and returns along the same path, with total traverse distance being 2d. This is clearly a minimum walkback case, since any traverse with more riding at a lesser radius has more consumables available for walkback and must meet the constraint. Thus any traverse to the left of the walkback distance line defined by the minimum riding traverse, as illustrated in Figure 3, is acceptable.

MSC has developed the concept of using these two lines for preliminary traverse constraint analysis (Reference 4). Any traverse within the envelope defined by the minimum riding line violates no emergency return constraints. No traverse can fall beyond the maximum riding line, and the area between these lines is termed indeterminate and requires a separate detailed calculation of consumables usage and walkback constraints for each traverse point which falls in this region. The inner line bounds the extreme case of guaranteed acceptable traverses, but since most traverses are not linear, radial, and minimum distance, a large proportion fall in the indeterminate region, requiring the detailed calculation which the traverse constraint envelope is designed to avoid. Thus, although rigorous, the utility of this concept is somewhat limited for preliminary traverse planning.

An alternate approach is to choose a ratio of riding to station time which corresponds reasonably well to the traverses which have been planned to date. Traverses do not tend to be particularly linear, as noted above, so a traverse consisting of a larger proportion of riding than the specified ratio would result in more consumables available for walkback while the actual distance from the LM would probably not increase significantly. A traverse with considerably less riding than the ratio chosen would provide less consumables for walkback, but, unless it was extremely linear and radial, would probably not reach the walkback limit. Experience shows an acceptable ratio to be about 50% riding and 50% science time.

Traverses which deviate greatly from the 50/50 ratio generally indicate a relatively poor allocation of resources. Excessively long traverses do not provide sufficient time to perform adequate sampling and scientific investigations. Very short traverses call into question the necessity for the LRV,

with its associated cost, weight, and time penalties. Due to the limitations imposed by the amount of consumables available for the nominal traverse, and the requirements for a reasonable provision of sufficient station time to perform comprehensive scientific exploration of the area, most traverses will fall within the envelope defined by the 50/50 riding/station time line. For those which are in its vicinity and have near the 50/50 ratio of times, this line is a considerably more accurate limit line than the accuracy of other assumptions associated with preliminary traverse planning. Those traverses which exceed this envelope can generally be considered to have violated the return constraints or to represent a poor mix of science and travel. Thus the use of this declining distance line may lack in rigor, but would seem to be adequate for preliminary planning purposes. For final traverse planning all of these envelopes are inadequate and detailed calculations, point by point, are required.

SUMMARY

The two groundrules which define the emergency return constraints can be transformed into a traverse constraint envelope. Although a portion of this envelope is nonlinear and depends upon the time history of consumables usage in the traverse, a simplifying assumption permits linearization. From this a maximum return distance versus EVA time plot may be drawn which presents these constraints graphically and can be used as a preliminary traverse planning aid. A full set of such plots for the currently accepted values of the parameters discussed is included in Reference 2. Increase of the value of the emergency return velocity or decrease of the rate at which consumables are used during emergency return results in an increase in the maximum return distance early in the EVA with the size of this increase declining as the EVA progresses. Increase of the total consumables available causes a uniform increase in the maximum return distance throughout the EVA, and increases in the ratio of riding time to station time provide a greater maximum return distance, with this effect becoming more significant as the EVA progresses. Provision of sufficient station time to perform comprehensive scientific exploration of the area and the EVA time limitations imposed by the total consumables available for the nominal traverse cause most traverses to fall well within the emergency return constraints. For those which do not, definition of the maximum return distance using a ratio of riding time to station time which corresponds to the traverses planned to date permits preliminary determination of walkback and rideback limits.

Peter Benjamin

2032-PB-cds P. Benjamin

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3. Lunar Surface Missions Guidelines, Apollo J Missions, MSC Rough Draft, August, 1970.

4. Thomas, K., Metabolic Relationships, presentation to MSC Lunar Surface Reference Mission Planning Meeting, October 8, 1970.

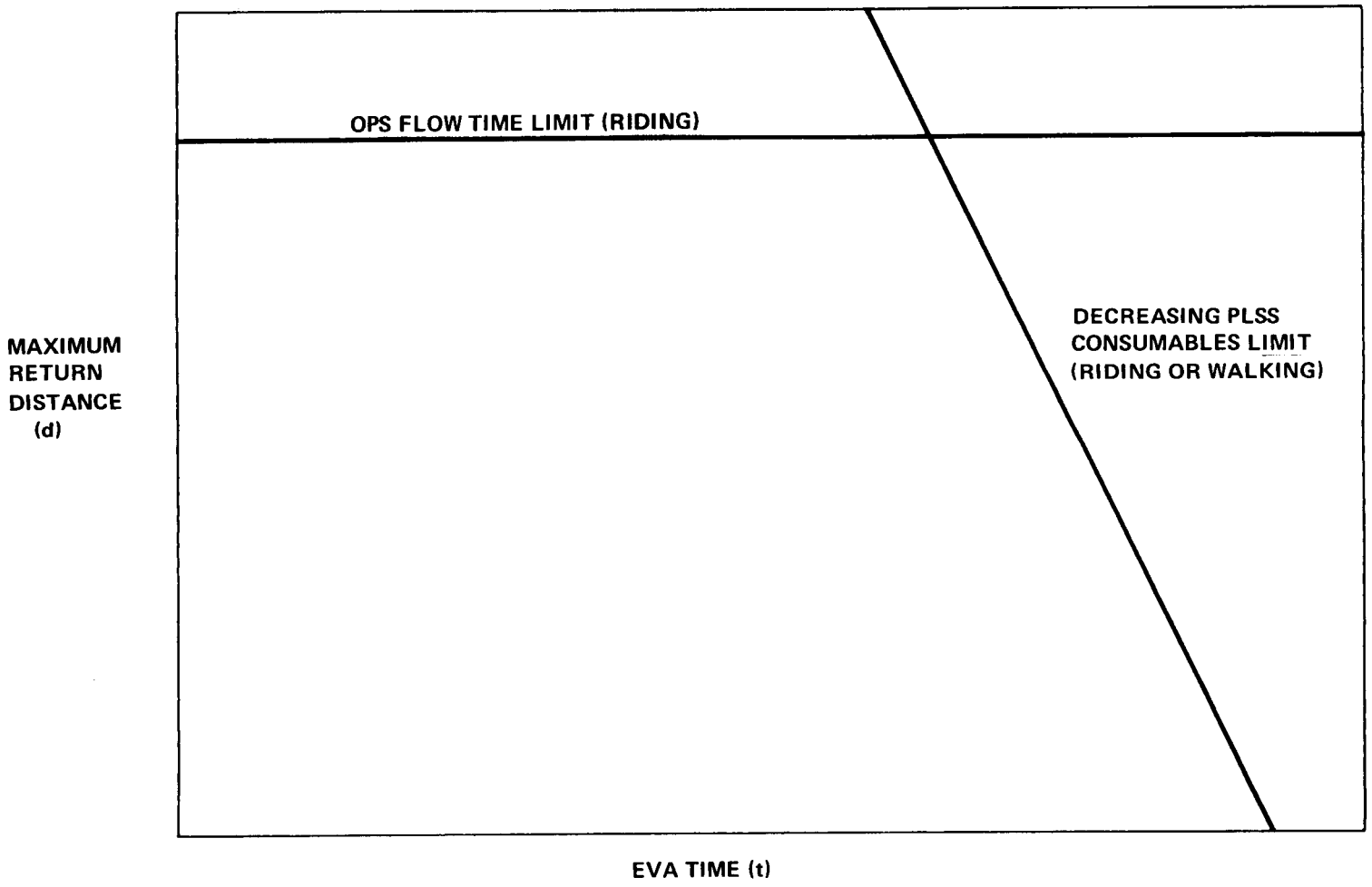
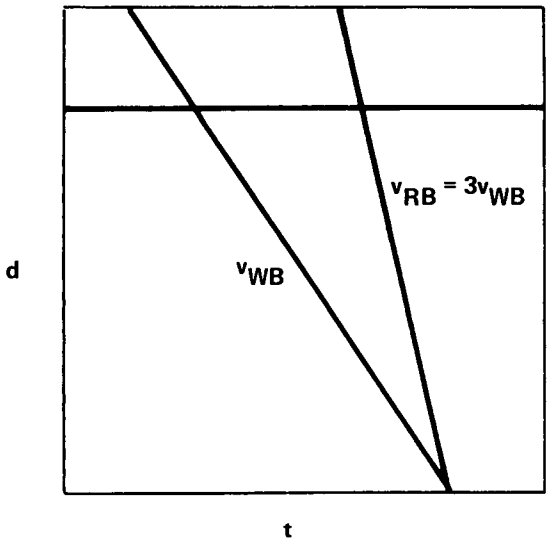
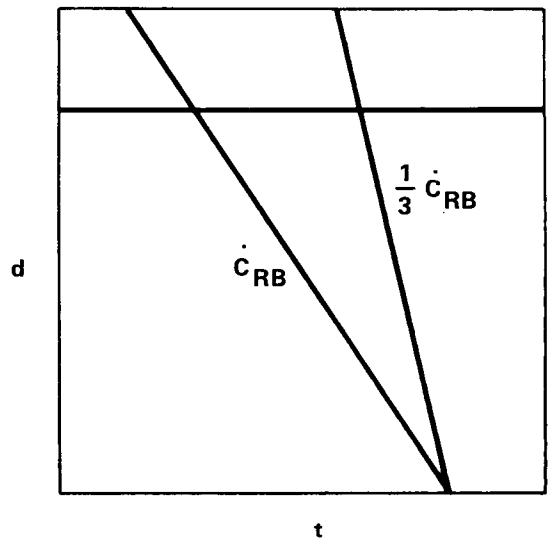


FIGURE 1 - TRAVERSE CONSTRAINT ENVELOPE

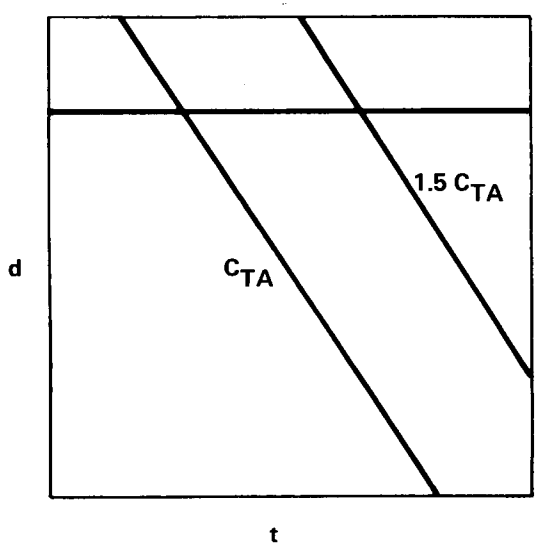
CASE 1
EMERGENCY RETURN VELOCITY VARIATIONS



CASE 2
EMERGENCY RETURN CONSUMABLE
USAGE RATE VARIATIONS



CASE 3
AVAILABLE CONSUMABLES VARIATIONS



CASE 4
RIDING TIME/SCIENCE TIME
VARIATIONS

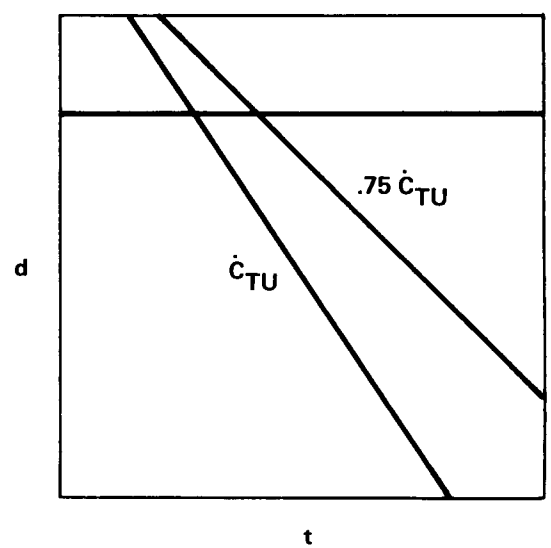


FIGURE 2 - MAXIMUM RETURN DISTANCE VARIATIONS

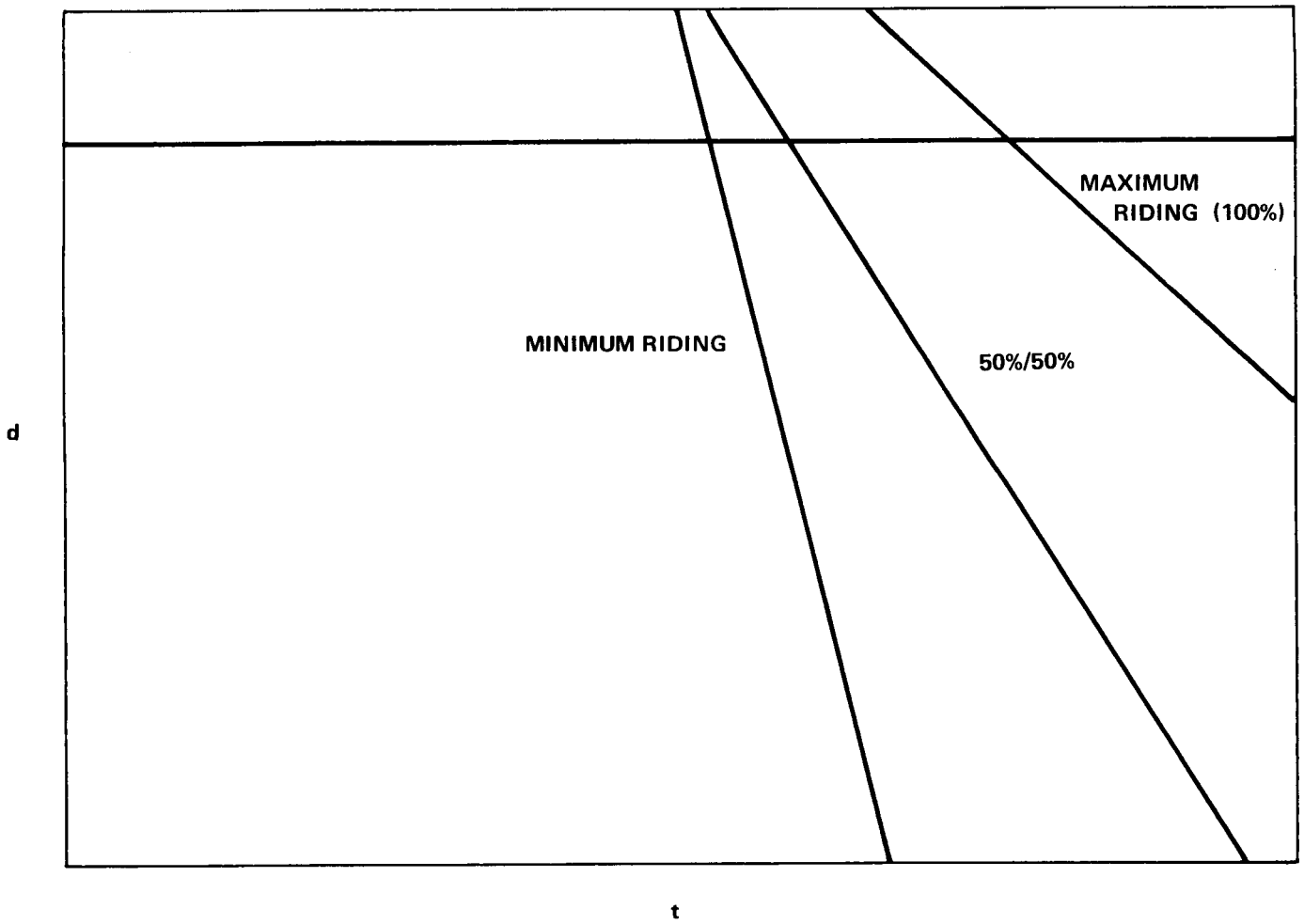


FIGURE 3 - MAXIMUM RETURN DISTANCE FORMATS IN CURRENT USE

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