Reply

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In his discussion, Dr. Abdullah raises five interesting points, on which I would like to comment very briefly.

1. *In the mathematical discussion of the pressure jump, we consider the jump as a real discontinuity in the pressure field. In the application of this theory to actual cases, we find that finite pressure gradients exist instead.* Essentially the point raised by Dr. Abdullah is whether a finite pressure gradient of 1.15 mb km^{-1} truly represents a discontinuity in pressure. It seems to me that we have here the familiar problem of adapting a mathematical model to a physical reality. It is a rare instance, indeed, when the mathematical model will represent the actual phenomenon in all respects. In the model used for the pressure jump line mechanism, there are several features which seem to depart from reality (these are discussed in greater detail in a recent paper[1]). To my mind, least significant of these features is whether a pressure gradient of 1.15 mb km^{-1} represents a real discontinuity in pressure, particularly in the scale of atmospheric motions normally considered. As described by Freeman,[2] gradients such as these appear as definite discontinuities on a surface synoptic map and should be analyzed as such.

2. *It is incorrect to apply the geostrophic wind relation to the jump zone.* This is an important observation, and I concur with Dr. Abdullah not only on this specific remark but on his entire discussion of this particular point. I regret, however, that some of the remarks in my original paper[3] were interpreted to imply that I suggested utilizing the geostrophic wind relation in the jump zone for computing actual wind speeds. The portion of that paper to which reference is made is but a descriptive account of a natural event. The point made there was that enormous speeds would result if particles remained in these gradients any length of time. The use of the geostrophic relation was but to give some estimate of the enormity of accelerations which could be developed.

3. *The jump cannot produce velocity changes right at the jump line, since there the horizontal velocity of individual particles is zero (for a fluid initially at rest).* The model which is used dictates that, at the jump line, there exists not only a discontinuity in pressure but also in velocity. Thus, with the passage of the pressure jump line there would be a marked increase in wind speed. This can be seen graphically from fig. 1, which is a representation on an *x-t* diagram of the formation of a pressure jump line from an elevation-type wave,[1] produced by an accelerating cold front. At A, where the wave is still an elevation-type wave, it is clear that at the leading edge of the wave the velocity is zero, and increases gradually as the wave passes. However, after the wave has partially "broken" and the pressure jump line has been formed, as for example at B, the passage of the jump line produces a sudden increase in wind speed from zero to u_3.

4. *In the atmosphere, winds will be produced by the intense turbulence of instability caused by the "breaking" process.* I concur in this remark and might add that in those instances where the latent instability is realized (*e.g.*, when thunderstorms are formed) the overturning process could also produce winds.

5. *The Coriolis force does not act right at the jump line but must act behind it.* This statement is essentially correct. The reason for the statement may be found in fig. 1. At A, which is behind the jump line, we note that the particle path line remains in the wave longer than one hour. On the other hand, the particle path line closer to the jump is in the wave only a matter of

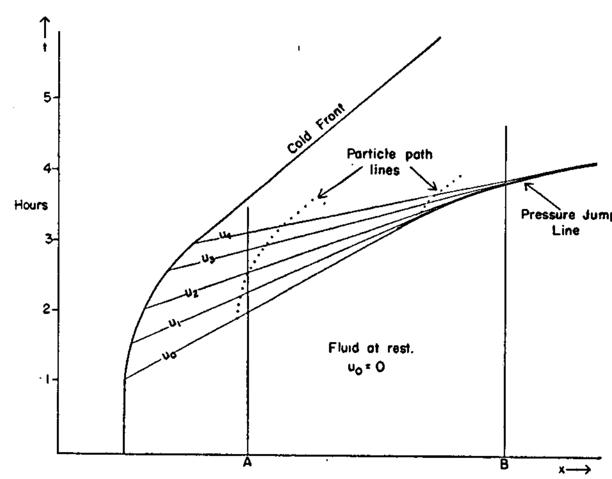

FIG. 1. Representation on *x-t* diagram of formation of pressure jump line from elevation-type wave which had been produced by accelerating cold front. Curve on cold front represents an acceleration between hours 1 and 3. Lines emanating from acceleration are characteristic lines along which inversion height and particle velocity are each constant. u_i represents particle velocity, and $u_4 > u_3 > u_2 > u_1 > u_0 = 0$. Area covered by characteristic lines represents progress of elevation-type wave until it "breaks" into pressure jump line. Particle path lines are indicated by dotted lines.

[1] M. Tepper, "On the application of the hydraulic analogy to certain atmospheric flow problems," *U. S. Wea. Bureau Res. Pap.*, No. 35, 1952.

[2] J. C. Freeman, Jr., "Map analysis in the vicinity of a pressure jump," *Bull. Amer. meteor. Soc.*, **31**, 324–325, 1950.

[3] M. Tepper, "A proposed mechanism for squall lines: the pressure jump line," *J. Meteor.*, **7**, 21–29, 1950.

minutes. Thus, in the early stages of the wave, when it is an elevation-type wave, the Coriolis-force effects are much more significant than at the later stages, when the characteristic lines have converged appreciably. In my recent paper,[1] the Rossby number $R_0 = v/fL$ is used as the criterion for estimating the relative importance of the Coriolis force. It was found that, in the vicinity of the jump, $R_0 \approx 25$, implying that the Coriolis-force effects may be neglected. At A, fig. 1, if we consider the particle speed to be about $\frac{1}{2}$ the wave speed, $R_0 \approx 5$. This indicates that the Coriolis-force effects are still relatively small there. It will be only in those regions where the Rossby number is still lower that there will be a deviation of the particles to the right. It follows that a one-dimensional model would be inadequate to cope with this situation.