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SOME NOTES ON METHODS OF ASSESSING VERTICAL SEPARATION STANDARDS

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SOME NOTES ON METHODS OF ASSESSING VERTICAL SEPARATION STANDARDS

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For my part in this discussion, I would like to talk about some of the methods that have been used to evaluate vertical separation standards. As shown in Figure 1, these methods include the vertical separation-loss method used by ICAO and IATA, the collision probability method, an error summation method, and the flight operational method used by IATA over the North Atlantic. As a background for this discussion, I would like first to define the errors that must be considered in the application of these methods; I would then like to indicate what we know of the magnitudes of these errors for the altitude range of 30,000 to 40,000 feet.

Figure 2 shows that the amount by which the cruise flight level of an airplane is displaced from its assigned altitude is due to the system error, which is the combined value of the instrument error and the static-pressure error. The static-pressure error is made up of a fixed error (which is the error that applies to a given type of aircraft, that is, the value in the flight manual) and a variable error (which is the difference between the actual error of an individual airplane and the value in the flight manual). The flight technical error is a measure of the random deviations of the airplane about its cruise flight level and the sum of this and the system error is the overall altimetry error.

The magnitude of the instrument error can vary, depending on the type of altimeter and on whether a correction is applied for the scale error. The fixed static-pressure error can also be corrected, either manually or by computer, and the value of the residual error will depend on which method is used.

The variable static-pressure error is generally not known and so cannot be corrected. The magnitude of the flight technical error will depend, for the most part, on whether the airplane is flown manually or by autopilot.

In considering these errors with respect to an assigned altitude separation, we first need a measure of the overall altimetry error that would be representative of all of the aircraft that might operate within a common altitude range. We then need to know how these errors should be combined for aircraft flying adjacent flight levels. Because of the difficulty of determining the overall altimetry errors of a large number of aircraft under routine operating conditions, an attempt was first made by ICAO to determine the magnitude of the individual errors and then to combine them by statistical procedures.

Figure 3 shows the values that were assigned to the individual errors by ICAO for an altitude of 40,000 feet (refs. 1 and 2). Each of the errors is assumed to have normal distribution and to have a value of 3σ, where σ is the standard deviation of the error. The significance of this 3σ value is that it is considered to represent the probable maximum value of the error; this is the error that would be equaled or exceeded in 0.3 percent of the cases or in three cases in a thousand.

The instrument error is that of a precision altimeter not corrected for the scale error, which, at this altitude, has a specified tolerance of 230 feet. The value of the fixed static-pressure error is the estimated residual error that would remain when manual corrections are made using correction cards. I would like to point out here that, with the best of present-day computers that apply corrections for both the instrument scale error and the fixed error, these two values can be reduced to 80 feet for an altitude of 40,000 feet (ref. 3). The variable static-pressure error is an estimated value based on rather limited information. The value of the flight technical error is based on tests in which a tabulation was made of the number and magnitude of the altitude deviations from the cruise flight level.

In more recent tests by the NASA, the time histories of altitude deviations were evaluated in terms of the deviation that would be equaled or exceeded for 0.3 percent of the cruise time. Because of the inclusion of the time element, we believe that this criterion represents a more meaningful measure of collision exposure than the probability of reaching a given altitude deviation.

On Figure 4, I have shown the NASA data that were obtained for routine airline operations under autopilot control in the altitude range up to 40,000 feet (ref. 4). The data on the left are for piston and turboprop aircraft and those on the right are for the turbojets. For the altitude range of 30,000 to 40,000 feet, the maximum value for the 10 jets was 225 feet. This means that, for 99.7 percent of their cruise times, all of the jets operated within ±225, or less, of their cruise flight levels. An important difference between the data of this investigation and those of the previous studies from which the ICAO value was derived is the fact that the distributions of the NASA data were not normal, but rather were of a type that included altitude deviations as large as 3 to 4 times the maximum value shown here. In addition, these large deviations occurred at a greater frequency than would be the case if the data had been normally distributed.

Figure 5 shows how the errors that were given on Figure 3 are combined by the vertical separation-loss method used by ICAO and IATA. On this figure, I have plotted one-half of the normal distributions of the instrument, static-pressure, and flight technical errors from one side of an assigned altitude. The 3σ values of each of the errors are scaled to an assigned separation of

1000 feet. When these three errors are combined by the root-mean-square procedure, the overall altimetry error for one aircraft becomes 620 feet, and when two 620-foot errors are combined by the same procedure, the overall error for two aircraft becomes 875 feet. This value is considered to represent the loss in vertical separation that would be equaled or exceeded 3 times in a thousand. When this 875-foot value is compared to the 1000-foot separation and an allowance of 50 feet is made for the size of the aircraft, there remains an actual separation, or margin of safety, of 75 feet. This analysis says nothing about the probability of collision; it only states that the actual separation will be 75 feet or less for a probability of 3 in one thousand.

On Figure 6, I have shown the same 620-foot error for each of two aircraft with the normal distributions plotted from assigned altitudes 1000 feet apart. For this arrangement of the normal curves, the probability of collision can be computed from the probabilities that the errors of the two aircraft would place them within each of the 50-foot segments for which the two curves overlap (ref. 5). For this 3σ value of 620 feet, the collision probability, for displacement in a vertical direction, would be 190 per million. This means that, for every million cases where two aircraft are along a vertical line with an assigned separation of 1000 feet, 190 collisions would occur.

Figure 7 shows how the collision probability varies with overall altimetry error for an assigned altitude separation of 1000 feet and an aircraft size of 50 feet. For an altimetry error of 500 feet, the collision probability is about 10 per million and for an error of 450 feet the probability is reduced to about 1 per million. These values apply only to the vertical separation case so that the actual probability of collision would presumably be much smaller since it would include the collision probabilities for lateral and longitudinal separation. This analysis shows the importance, however, of reducing the overall altimetry error to a value less than one-half the separation minimum.

On Figure 8, I have examined the possibility of achieving overall altimetry errors less than 500 feet at an altitude of 40,000 feet on the basis of our present capability for automatic correction of the instrument and fixed static-pressure errors and in the light of our present knowledge of the flight technical error. Here the instrument and the static-pressure errors have been combined as a system error since, for this case, I have assumed the use of a servo-correction system for correcting both of the errors. The value of the correction error is 80 feet and the variable error of the static-pressure system is the same 250-foot value that was estimated by ICAO; the root-mean-square combination of these errors yields a system error of 262 feet. The flight technical error is the maximum value (i.e., 225 feet) that was measured for the jet transports in the NASA study. Since this flight technical error is not normally distributed, it cannot be combined with the system error by the root-mean-square procedure. For this reason, I have taken the much more conservative approach and have added the two errors directly as shown on Figure 8. Although the resulting value is less than 500 feet, I would like to emphasize that this result is based on the assumptions that: (1) the variable static-pressure errors of all aircraft are, in fact, normally distributed with a 3σ value of 250 feet, (2) the fixed static-pressure errors of all aircraft types are determined with an accuracy such that the corrections for these errors and the instrument errors can be represented by a 3σ value of 80 feet, and (3) the large flight technical errors that were found in the NASA study can be reduced to values approaching the 225-foot value shown here (ref. 6).

Figure 9 shows the results of the vertical-separation study that was conducted in 1963 by the airlines over the North Atlantic (ref. 7). On the basis of this study, IATA concluded that overall altimetry errors less than 500 feet are being realized with present equipment in the altitude range between 30,000 and 40,000 feet. The system errors in this study were measured with altimeter systems that were both servo and manually corrected but with the majority of measurements being obtained from servo-corrected systems. The measured value of 312 feet would, thus, appear to be in reasonable agreement with the 262-foot value assumed for a servo-correction system in the analysis of Figure 8. The flight technical errors, however, were derived from measurements with the aircraft in steady flight and, for this reason, I would question whether the distribution of these flight technical errors (from which a 3σ value of 190 feet was deduced) would include the large altitude deviations that were found in the NASA study.

On the basis of this review, it is apparent that an assessment of a vertical separation standard will depend on the values assigned to the individual errors, on the procedure used to combine the errors, and on the manner in which the overall error is considered in reference to the separation standard. From the standpoint of conservatism, it would appear that the system error and the flight technical error should be combined by simple summation and that the resulting overall error should be compared to the separation standard in terms of collision probability. Finally, from the standpoint of minimizing collision risk, the overall errors of all aircraft should be kept to values less than one-half the separation standard regardless of the probabilities of collision for lateral and longitudinal separation.

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- VERTICAL SEPARATION LOSS
- COLLISION PROBABILITY
- ERROR SUMMATION
- FLIGHT OPERATIONAL

NASA

Figure 1.- Vertical separation assessment methods.

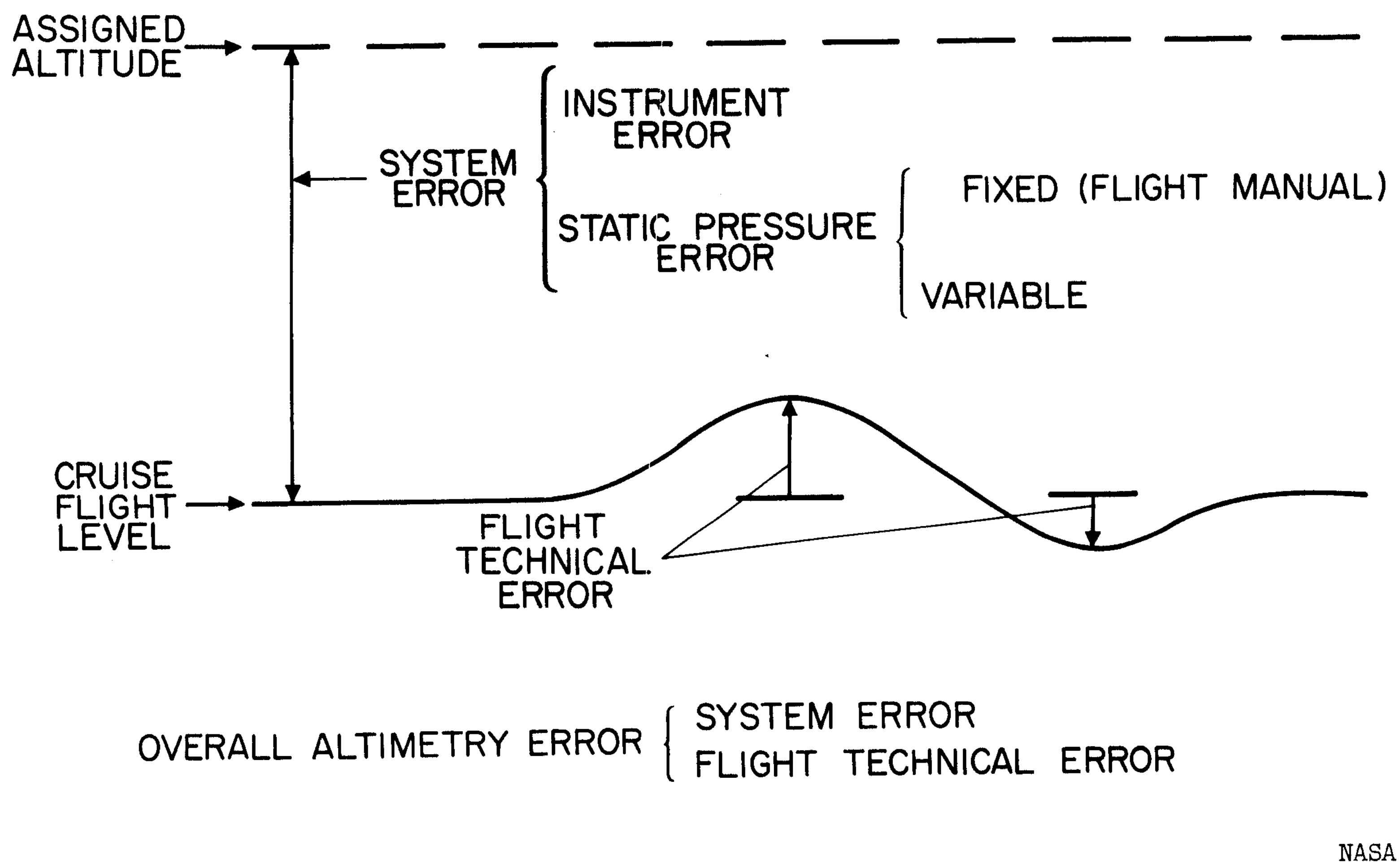
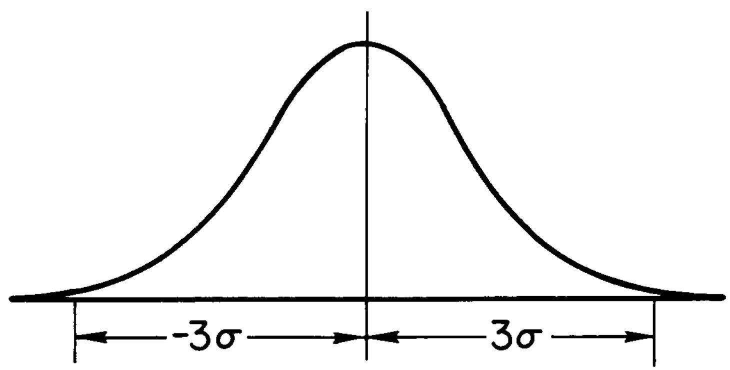


Figure 2.- Pressure altimetry errors.

(ICAO ESTIMATES)

	3σ = VALUES, FT
INSTRUMENT (UNCORRECTED)	250
STATIC PRESSURE	
FIXED (MANUAL CORRECTION)	50
VARIABLE	250
FLIGHT TECHNICAL	500



σ = STANDARD DEVIATION
3σ = PROBABLE MAX. ERROR

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Figure 3.- Errors at 40,000 feet.

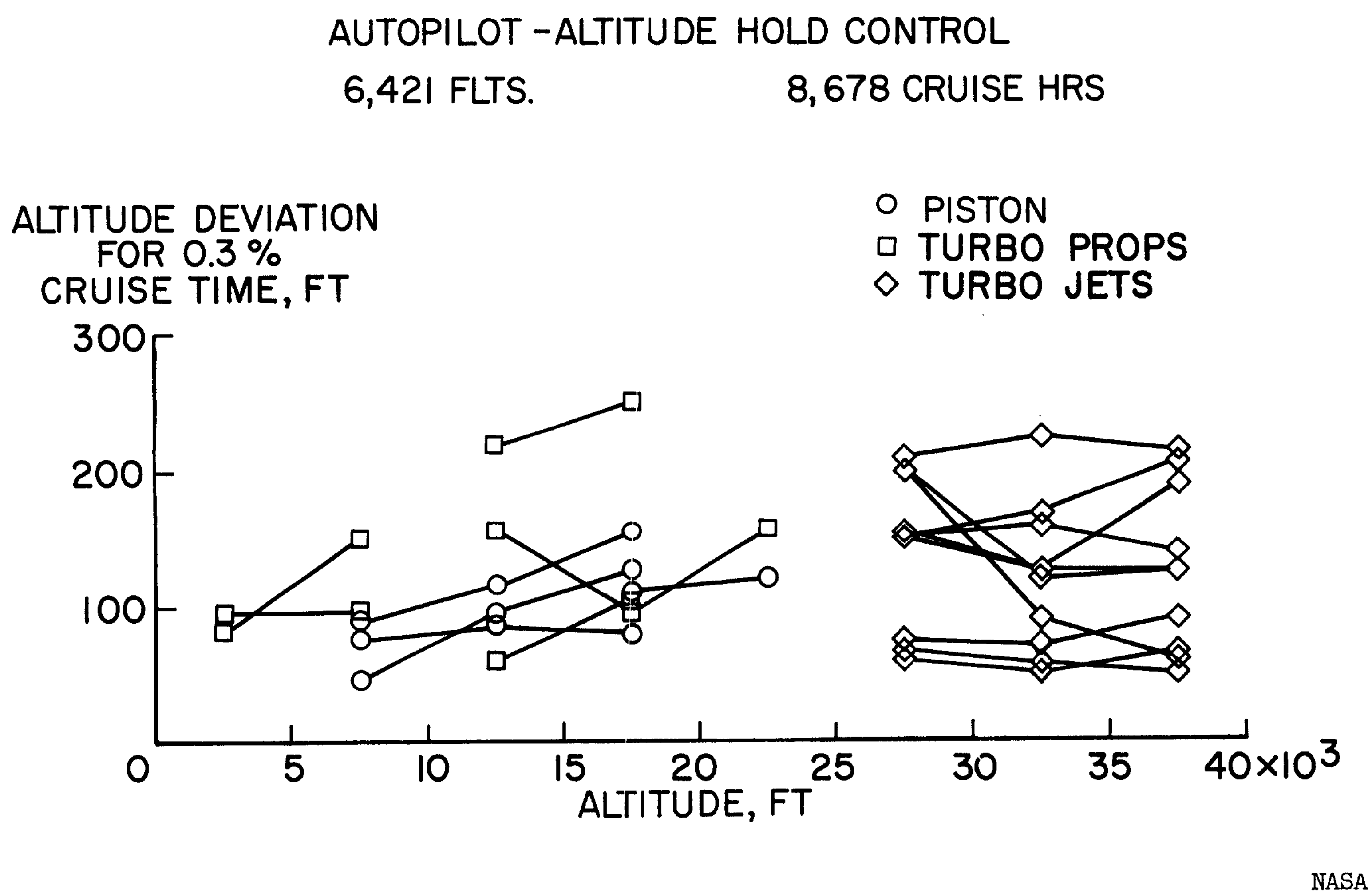

Figure 4.- Flight technical errors of 19 civil transports.

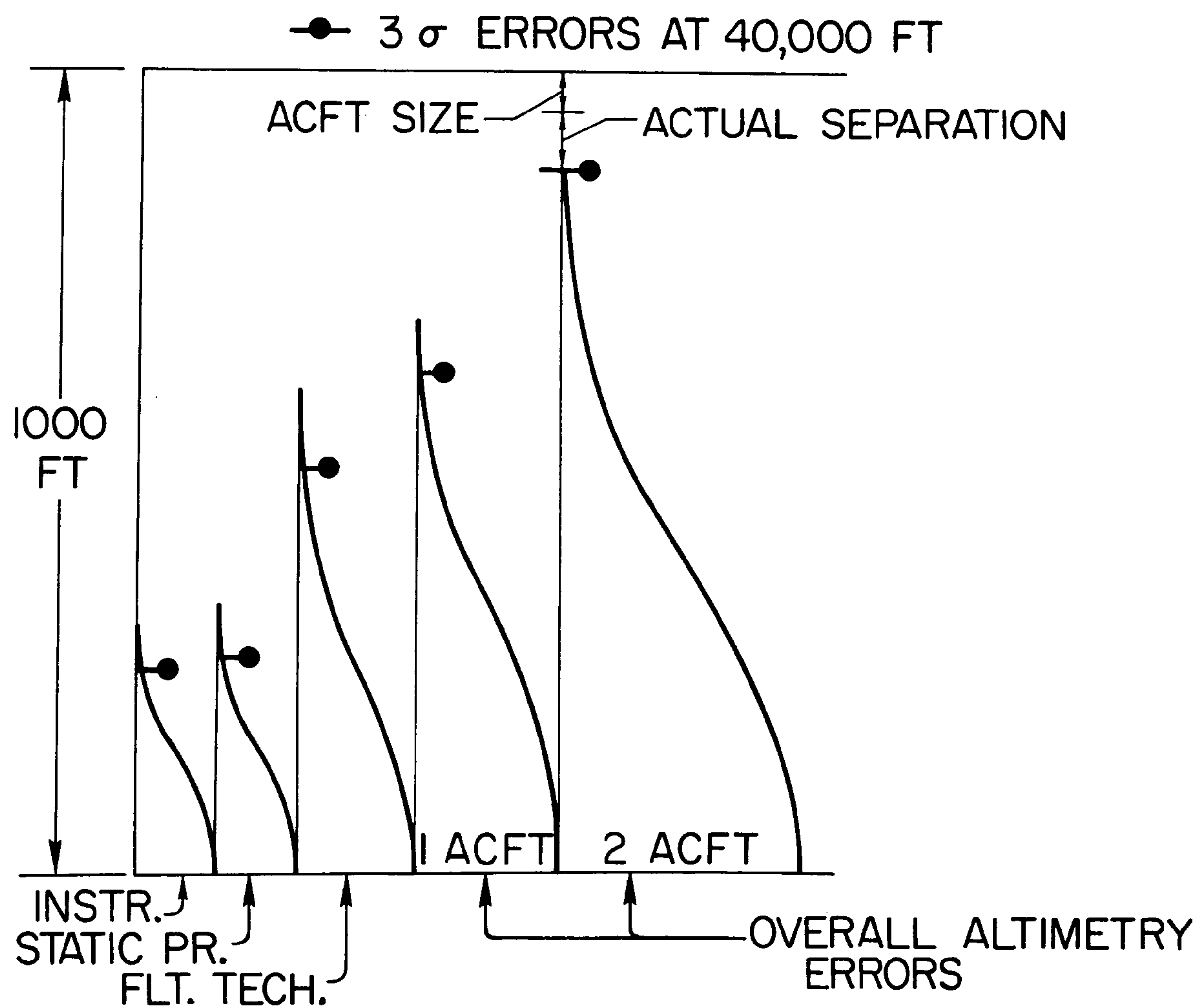

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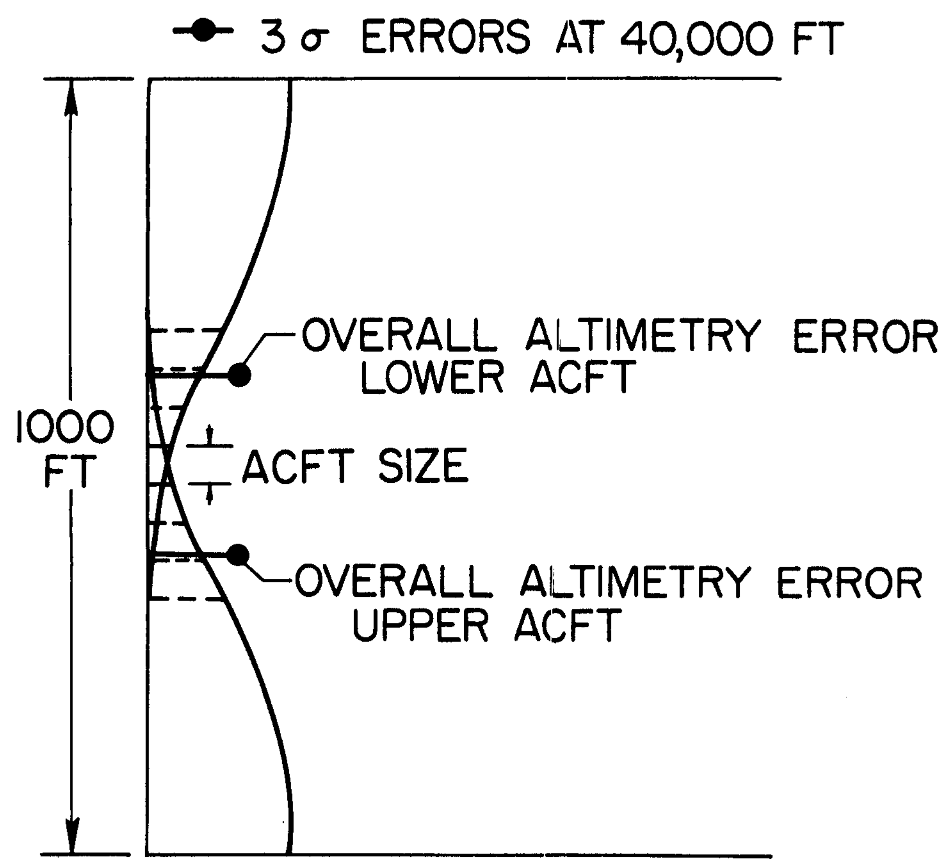
Figure 5.- Vertical separation loss method.



NASA

Figure 6.- Collision probability method.

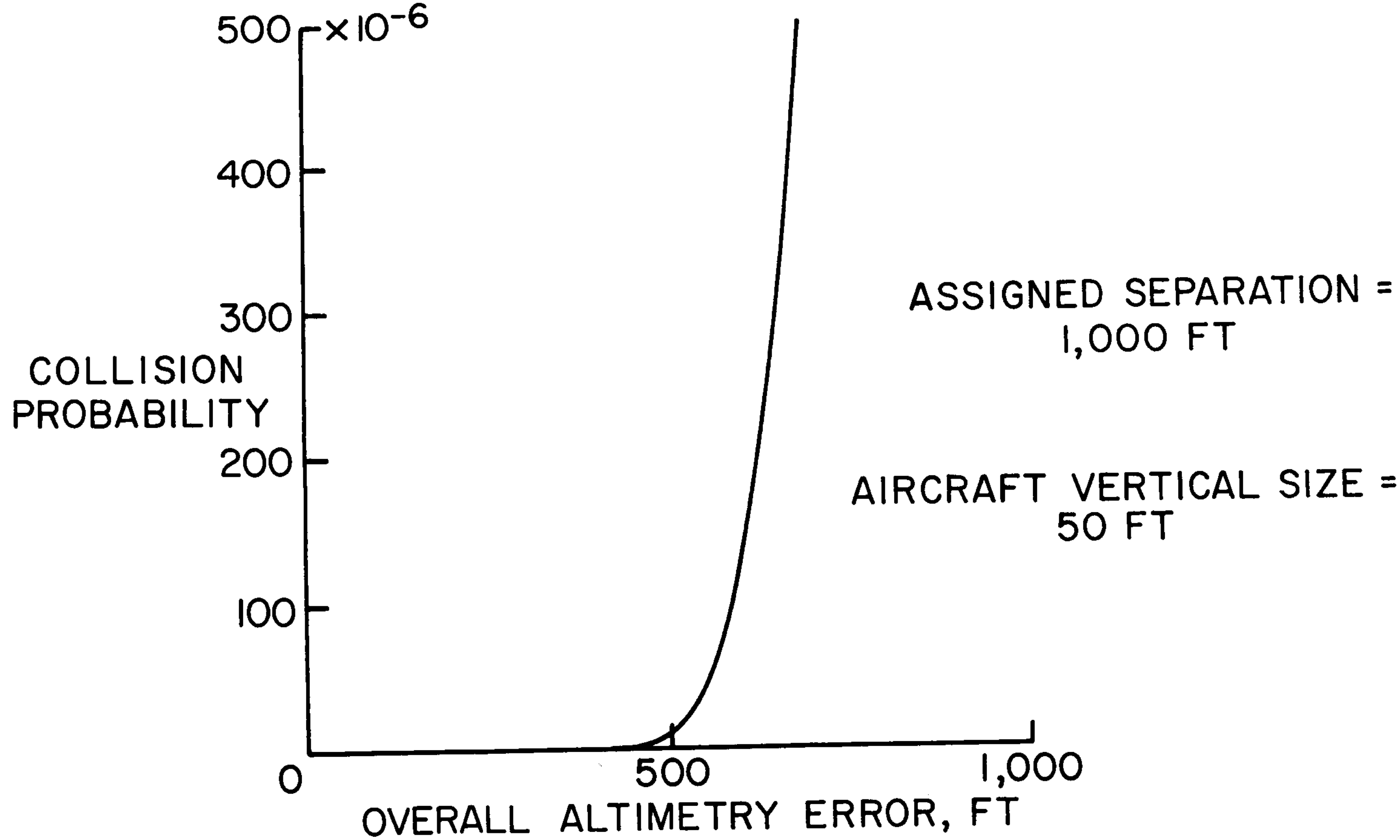


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Figure 7.- Collision probability for vertical displacement.

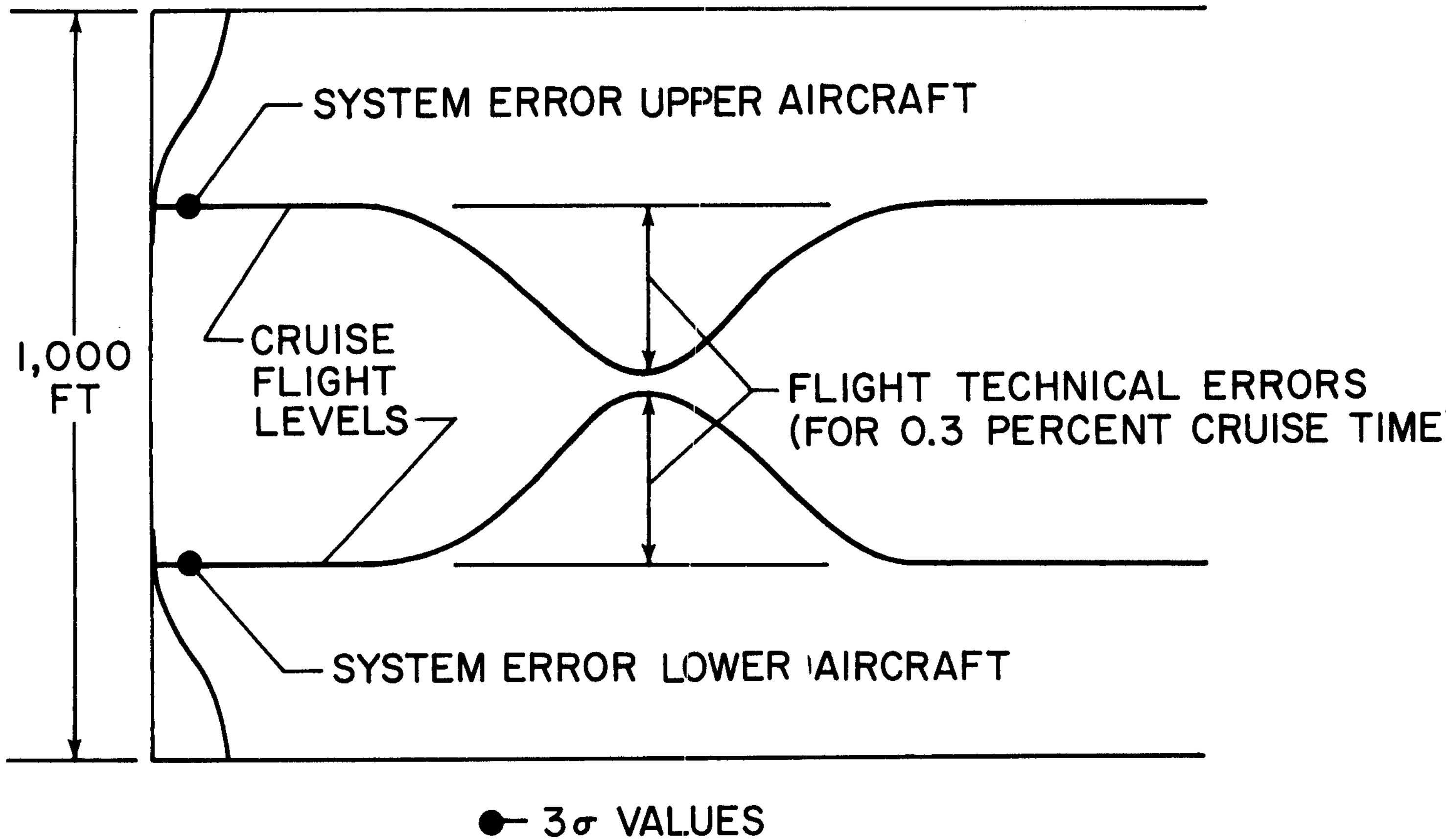

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Figure 8.- Error summation method.

NORTH ATLANTIC REGION
29,000 TO 41,000 FT
1854 FLIGHTS

ERRORS (1 AIRCRAFT)	3σ VALUES, FT
SYSTEM	312
FLIGHT TECHNICAL	190
OVERALL ALTIMETRY	366

NASA

Figure 9.- IATA flight operational method.

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