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# A PRACTICAL FIELD WIND COMPENSATION TECHNIQUE FOR UNGUIDED ROCKETS

by
Gordon L. Dunaway



ATMOSPHERIC SCIENCES RESEARCH OFFICE
WHITE SANDS MISSILE RANGE, NEW MEXICO



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UNITED STATES ARMY ELECTRONICS COMMAND

# A PRACTICAL FIELD WIND COMPENSATION TECHNIQUE FOR UNGUIDED ROCKETS

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ABSTRACT

An accurate and rapid wind compensation technique for the field determination of launcher settings for unguided rockets is presented. The method was tested with a five-degree-of-freedom trajectory simulation program using several observed wind profiles. The results of five computer tests for an Aerobee 150 show that the maximum theoretical impact miss was 3.8 statute miles when the theoretical impact displacement was 147.4 statute miles. In three tests for an Athena (two-stage), the maximum theoretical impact miss was 5.4 statute miles when the theoretical impact displacement due to the wind was 141.8 statute miles.

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## INTRODUCTION

Since the beginning of rocketry, the need has existed for a rapid and practical method of applying wind compensation corrections to unguided rockets. This is particularly true in the case of unguided rockets carrying scientific payloads to extremely high altitudes when safety and recovery considerations place constraints on the impact area and in the case of tactical missiles carrying warheads to predetermined targets.

Utilization of high-speed computers during the past few years has made possible the development of highly sophisticated rocket trajectory simulation models. When accurate rocket descriptors, atmospheric data and initial conditions are used in these models, the rocket trajectories from launch to impact can be closely simulated.

These trajectory simulation models have been the basis for the development of various techniques (1-11) for wind effect compensation, each showing certain advantages and disadvantages in operational usage.

An acccurate operational procedure is the meteorological real-time system (12,13,14) developed by the Atmospheric Sciences Laboratory at White Sands Missile Range (WSMR), New Mexico. This procedure is used in the support of Athena rockets which are fired from Green River, Utah, to impact on WSMR. For this system, data from wind measuring instrumentation at the launch site are transmitted over commercial data lines to a digital computer at the headquarters area of the missile range. The computer reduces the wind data, applies them to a trajectory model, computes launcher settings using iterative techniques, and prints out a complete rocket trajectory simulation for each wind profile considered. This type of system would be desirable for all unguided rocket firings; however, because of cost and inaccessibility to remote sites, the real-time system may be impractical in some cases.

One of the most widely accepted field wind compensation techniques to date is the graphical method developed by James (3), in which trajectories are computed to determine the launcher setting corrections necessary to compensate for given wind profiles. Nomograms which show ballistic wind speed and direction versus desired launcher azimuth and elevation angles are used for the given rocket. The method works quite well for high-angle trajectories; however, there is some problem in the interpolation of the wind speed on the nomograms, and the validity of the wind-weighting factors suggested for this method is questioned for low-angle trajectories. Also, additional time is required to convert the ballistic wind components to speed and direction, and time is of the essence due to the low-level wind variability.

The technique presented in this report is similar to that of James (3). Instead of nomograms, tables of ballistic wind components versus desired launcher azimuth and elevation angles, theoretical no wind impact, and theoretical range and cross displacement of impact due to wind for a given range and interval of ballistic wind components are used. The basic theory used with this technique is very close to that described by Duncan and Engebos (7).

The wind-weighting technique used with this system is based on deviations of the rocket impacts due to wind acting on the rocket during its ascent and descent through various altitude layers (10), whereas the wind-weighting for the James method is based on cross-wind-induced angular deviations at the altitudes to which the wind effect is considered to be significant.

## DISCUSSION

The major weaknesses in the field wind compensation techniques (7,15) used in the past at WSMR have been: (1) the assumption of linear relationships between ballistic wind components and impact displacements due to wind and (2) the assumption of linear relationships between small changes in elevation angles and changes in impact range.

When the rockets are launched near the vertical, these assumptions are reasonably valid, and the method can be used with a fair degree of accuracy. As the nominal elevation angle is lowered, the results based on these assumptions deteriorate markedly.

Experiments have shown that when the nominal launcher elevation angle is greater than that required for a maximum range trajectory, the wind-weighting curve derived from cross-wind-induced impact deviations is very similar to that derived from range-wind-induced impact deviations. A high degree of accuracy is obtained if a single set of wind-weighting factors is used to compute both components of ballistic winds for this type of trajectory.

As the nominal elevation angle is decreased from the angle required for a maximum range trajectory, the wind-weighting curve for range winds begins to differ significantly from that for cross winds. Thus, separate sets of wind-weighting factors should be applied to the range-wind and cross-wind components in ballistic wind computations for trajectories of this type.

## DEVELOPMENT

Assume a right-hand coordinate system with the origin at the launcher. The y-axis is positive in the direction of the firing line, the x-axis is positive to the right of the firing line, and the z-axis is positive upward. Let $\gamma$ and $\psi$ represent angles in the vertical planes parallel and perpendicular to the firing line, respectively (7). See Figure 1.

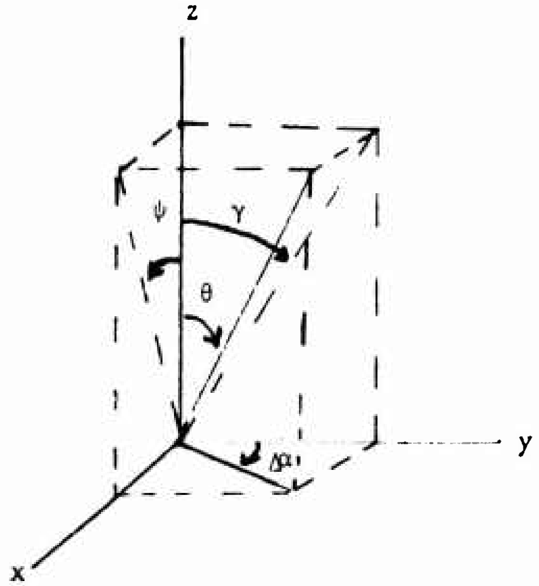


Figure 1

Then,

$$\gamma_L = \tan^{-1} [\tan \theta_L \cos (\alpha_L - \alpha_{Lo})]$$

and

$$\psi_L = \tan^{-1} [\tan \theta_L \sin (\alpha_L - \alpha_{Lo})] \qquad (1)$$

where $\gamma_L$ and $\psi_L$ are the launcher angles in the vertical planes parallel and perpendicular to the firing line referenced to the nominal launcher azimuth, $\alpha_{Lo}$ is the nominal launcher azimuth, $\alpha_L$ is the actual launcher azimuth, and $\theta_L$ is the launcher elevation angle from vertical.

Similarly

$$\gamma_B = \tan^{-1} [\tan \theta_B \cos (\alpha_B - \alpha_{Lo})]$$

and

$$\psi_B = \tan^{-1} [\tan \theta_B \sin (\alpha_B - \alpha_{Lo})] \qquad (2)$$

where $\gamma_B$ and $\psi_B$ are the angles in the vertical planes parallel and perpendicular to the firing line of the velocity vector at burnout referenced to the nominal launcher azimuth, $\alpha_L$ is the azimuth of the velocity vector at burnout, and $\theta_B$ is the elevation angle from vertical of the velocity vector at burnout.

Let U and V represent the east-west and north-south components of ballistic wind, respectively. Then,

$$U_L = U \cos \alpha_{Lo} - V \sin \alpha_{Lo}$$

and

$$V_L = U \sin \alpha_{Lo} - V \cos \alpha_{Lo} \qquad (3)$$

where $U_L$ and $V_L$ are the cross and range components of ballistic wind referenced to the nominal launcher azimuth.

The following assumptions are used in the development of this technique:

1. Changes in $\gamma_L$ vary linearly with respect to changes in $\gamma_B$ for no wind trajectories, although the relationship may be different for increasing than for decreasing changes.

2. Changes in $\psi_L$ vary linearly with respect to changes in $\psi_B$ for no wind trajectories.

3. Changes in $\gamma_B$ vary linearly with respect to changes in $V_L$, although the changes may be different for a head-wind than for a tail-wind.

4. Changes in $\psi_B$ vary linearly with respect to changes in $U_L$.

Factors relating changes in launcher angles to changes in burnout angles can be determined using the first two assumptions and a small set of no wind trajectory simulations with appropriate launcher settings:

$$\left(\frac{d\gamma_L}{d\gamma_B}\right)_t = \frac{\gamma_{Lt} - \gamma_{Lo}}{\gamma_B - \gamma_{Bo}}$$

$$\left(\frac{d\gamma_L}{d\gamma_B}\right)_h = \frac{\gamma_{Lh} - \gamma_{Lo}}{\gamma_B - \gamma_{Bo}}$$

and

$$\left(\frac{d\psi_L}{d\psi_B}\right)_c = \frac{\psi_L - \psi_{Lo}}{\psi_B - \psi_{Bo}} \qquad (4)$$

where the subscripts t and h represent changes in $\gamma$ with respect to decreasing or increasing elevation angles as would be experienced with a tail-wind or a head-wind, respectively, and the subscript c represents changes in $\psi$ as would be experienced with a cross-wind.

Similar factors relating changes in burnout angles to changes in ballistic wind can be determined using the third and fourth assumptions and a small set of trajectory simulations with nominal launcher settings and appropriate wind inputs:

$$\left(\frac{d\gamma_B}{dV_L}\right)_t = \frac{\gamma_{Bt} - \gamma_{Bo}}{V_{Lt}}$$

$$\left(\frac{d\gamma_B}{dV_L}\right)_h = \frac{\gamma_{Bh} - \gamma_{Bo}}{V_{Lh}}$$

and

$$\left(\frac{d\psi_B}{dU_L}\right)_c = \frac{\psi_B - \psi_{Bo}}{U_L} \qquad (5)$$

Combining the factors from Eq. (4) with those from Eq. (5), we obtain the factors which will give the desired change in $\gamma_L$ with respect to a change in tail-wind or head-wind component of ballistic wind and the desired change in $\psi_L$ with respect to a change in cross-wind component of ballistic wind:

$$\left(\frac{d\gamma_L}{dV_L}\right)_t = \left(\frac{d\gamma_L}{d\gamma_B}\right)_t \cdot \left(\frac{d\gamma_B}{dV_L}\right)_t$$

$$\left(\frac{d\gamma_L}{dV_L}\right)_h = \left(\frac{d\gamma_L}{d\gamma_B}\right)_h \cdot \left(\frac{d\gamma_B}{dV_L}\right)_h$$

and

$$\left(\frac{d\psi_L}{dU_L}\right)_c = \left(\frac{d\psi_L}{d\psi_B}\right) \cdot \left(\frac{d\psi_B}{dU_L}\right)_c \qquad (6)$$

These factors, Eq. (6), are used as the basis for launcher angle corrections in the following manner:

$$\Delta \gamma_L = V_L \left(\frac{d\gamma_L}{dV_L}\right)_t , \quad V_L < 0$$

$$\Delta \gamma_L = V_L \left(\frac{d\gamma_L}{dV_L}\right)_h , \quad 0 \leq V_L$$

and

$$\Delta \psi_L = U_L \left(\frac{d\psi_L}{dU_L}\right)_c \tag{7}$$

The desired launcher angles referenced to the nominal launcher azimuth then become:

$$\gamma_L = \gamma_{Lo} - \Delta \gamma_L$$

and

$$\psi_L = \Delta \psi_L \tag{8}$$

The angles are then converted to azimuth and elevation angles in the following manner:

$$\Delta \alpha_L = \tan^{-1} \left[\frac{\tan \psi_L}{\tan (\gamma_{Lo} - \Delta \gamma_L)}\right]$$

$$\alpha = \alpha_{Lo} - \Delta \alpha_L$$

and

$$\theta = \tan^{-1} \left[\frac{\tan (\gamma_{Lo} - \Delta \gamma_L)}{\cos (\Delta \alpha_L)}\right] \tag{9}$$

where $\alpha$ and $\theta$ are the desired launcher azimuth and elevation angles, respectively.

The impact range versus launcher elevation angle for a no wind trajectory can be closely approximated over reasonable interval by the parabola,

$$R_n = \theta(a\theta - b) \tag{10}$$

where $R_n$ is the no wind range, θ is the launcher elevation angle from vertical and a and b are constants which can be determined from a small set of no wind trajectory simulations.

It is desirable to have a method for obtaining theoretical impact displacements due to wind so that the expected impact dispersion due to wind variability may be assessed.

Close approximations to the theoretical impact displacements due to wind are given by,

$$Y_{Lw} = Y_{LO} - R_n \cos \alpha_L - C_y$$

and

$$X_{Lw} = X_{LO} - R_n \sin \alpha_L - C_x \qquad (11)$$

where $Y_{Lw}$ and $X_{Lw}$ are the range and cross components of the theoretical impact displacement due to wind, $Y_{LO}$ and $X_{LO}$ are the range and cross components of the nominal impact, and $C_y$ and $C_x$ are the range and cross components of the theoretical impact displacement due to the rotation of the earth.

## EVALUATION TESTS

To evaluate the accuracy of the technique, tests were performed using wind measurements and theoretical rocket descriptors from actual WSMR support missions. A five-degree-of-freedom trajectory simulation program (10) and a high-speed computer were used for these tests.

One series was performed for an Aerobee 150 vehicle with a nominal elevation angle of 3 degrees from vertical. Five observed wind profiles (Appendix A) were used for these tests.

Launcher settings derived using this technique, the observed wind profiles, and theoretical rocket performance parameters were put in the program and trajectories were computed. The impacts from the computer trajectories were compared with the nominal impacts to determine the accuracy of the technique. The results are presented in Table I.

Results of five tests for the Aerobee 150 indicated a maximum theoretical impact miss from the use of this method of 3.8 statute miles, which occurred when the theoretical impact displacement due to wind was 147.4 statute miles.

The Aerobee 150 results were so encouraging that similar tests were run for a higher performance vehicle (Athena, two-stage) with a

TABLE I

Results from tests of Aerobee 150 Launcher Settings for Various Wind Profiles

| CASE | BALLISTIC WIND COMPONENTS (MPH) | | LAUNCHER SETTINGS COMPUTED USING THIS TECHNIQUE (DEGREES) | | THEORETICAL IMPACT FROM 5-DEGREE-OF FREEDOM TRAJECTORY SIM. (ST. MILES) | | THEORETICAL IMPACT MISS DISTANCE FROM THE USE OF THIS TECHNIQUE (ST. MILES) | | THEORETICAL IMPACT DISPLACEMENT DUE TO WIND, BASED ON A UNIT WIND EFFECT (ST. MILES) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | RANGE | CROSS | AZ | EL | RANGE | CROSS | RANGE | CROSS | RANGE | CROSS |
| NOMINAL | 0.00 | 0.00 | 360.0 | 87.0 | 56.70 | -5.56 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1 | -9.38 | -10.43 | 024.8 | 84.5 | 57.39 | -4.44 | 0.69 | 1.12 | -38.56 | -44.23 |
| 2 | 11.91 | 1.46 | 321.8 | 89.5 | 57.33 | -5.00 | 0.63 | 0.56 | 48.96 | 6.20 |
| 3 | 0.72 | -26.42 | 064.4 | 83.4 | 57.24 | -2.40 | 0.54 | 3.16 | 2.97 | -112.00 |
| 4 | -5.29 | -34.39 | 061.8 | 81.3 | 57.73 | -1.95 | 1.03 | 3.61 | -21.76 | -145.82 |
| 5 | -3.58 | - 2.23 | 007.5 | 86.2 | 55.41 | -4.33 | -1.29 | 1.23 | -14.73 | -9.45 |

NOTE: All wind and impact data are referenced to the no wind launcher azimuth.

nominal elevation angle of 15 degrees from vertical. Three observed wind profiles (Appendix B) were used for these tests. The results are presented in Table II; the maximum theoretical impact miss was 5.4 statute miles which occurred when the theoretical impact displacement due to wind was 141.8 statute miles.

## CONCLUSIONS

This wind compensation technique is believed to be practical, not only as an accurate field wind compensation technique, but also as a close first approximation to be used in meteorological real-time support programs.

Once the tables have been constructed for a given rocket, the only additional data needed to look up corrected launcher settings are the ballistic wind components. Thus, on-the-site calculations are minimized, and corrected launcher settings can be determined rapidly.

TABLE II

Results from Tests of Athena Launcher Settings for Various Wind Profiles

| CASE | BALLISTIC WIND COMPONENTS (MPH) | | LAUNCHER SETTINGS COMPUTED USING THIS TECHNIQUE (DEGREES) | | THEORETICAL IMPACT FROM 5-DEGREE-OF-FREEDOM TRAJECTORY SIM. (ST. MILES) | | THEORETICAL IMPACT MISS DISTANCE FROM THE USE OF THIS TECHNIQUE (ST. MILES) | | THEORETICAL IMPACT DISPLACEMENT DUE TO THE WIND, BASED ON A UNIT WIND EFFECT (ST. MILES) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | RANGE | CROSS | AZ | EL | RANGE | CROSS | RANGE | CROSS | RANGE | CROSS |
| NOMINAL | 0.00 | 0.00 | 151.7 | 75.0 | 443.96 | 13.39 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1 | 0.79 | 18.94 | 136.4 | 74.6 | 444.87 | 13.62 | 0.91 | 0.23 | 1.45 | 119.38 |
| 2 | 13.79 | 17.79 | 134.6 | 77.0 | 444.18 | 9.54 | 0.22 | -3.85 | 25.31 | 112.13 |
| 3 | 6.73 | 22.42 | 132.4 | 74.5 | 446.62 | 8.71 | 2.66 | -4.68 | 12.35 | 141.31 |

NOTE: All wind and impact data are referenced to the no wind launcher azimuth.

## REFERENCES


1. Daw, H. A., "A Wind Weighting Theory for Sounding Rockets Derivable from the Rocket Equations of Motion," Physical Sciences Laboratory, New Mexico State University, University Park, New Mexico, November 1958.

2. Lewis, J. V., "The Effect of Wind and Rotation of the Earth on Unguided Rockets," BRL Report No. 685, Aberdeen Proving Ground, Maryland, 1959.

3. James, Robert L., Jr. and Ronald J. Harris, "Calculation of Wind Compensation for Launching of Unguided Rockets," NASA TND-645. April 1961.

4. Hennigh, Keith E., "Field Wind Weighting and Impact Prediction Procedure for Unguided Rockets," Physical Sciences Laboratory, New Mexico State University, University Park, New Mexico, for NASA Goddard Space Flight Center, March 1962.

5. Hennigh, Keith E., "Modifications to Field Wind Weighting and Impact Procedure for Unguided Rockets," NASA TND-645, April 1962.

6. Duncan, Louis D., Ronald J. Ensey, and Bernard F. Engebos, "Athena Launch Angle Determinations," ERDA 187, Atmospheric Sciences Laboratory, White Sands Missile Range, New Mexico, September 1964.

7. Duncan, Louis D., and Bernard F. Engebos, "Techniques for Computing Launcher Settings for Unguided Rockets," ECOM 5077, Atmospheric Sciences Laboratory, White Sands Missile Range, New Mexico, September 1966.

8. Walter, Dr. Everett L., "Six-Variable Ballistic Model for a Rocket," U. S. Army Signal Missile Support Agency, White Sands Missile Range, New Mexico, June 1962.

9. Duncan, Louis D., and Ronald J. Ensey, "Six-Degree-of-Freedom Digital Simulation Model for Unguided Fin-Stabilized Rockets," ERDA 196, Atmospheric Sciences Laboratory, White Sands Missile Range, New Mexico, November 1964.

10. Cochran, Vertis C., Edward M. D'Arcy, and Florencio Ramirez, "Digital Computer Program for Five-Degree-of-Freedom Trajectory," ECOM 5036, Atmospheric Sciences Laboratory, White Sands Missile Range, New Mexico, March 1966.

11. Walker, R. L., "Improved Method of Obtaining Launcher Settings," Space Data Corporation, September 1966.

12. Duncan, Louis D., "Real-Time Meteorological System for Unguided Rocket Impact Prediction," Tech Report ERDA-55, USAERDA, White Sands Missile Range, New Mexico, July 1963.

13. Rachele, Henry, and Louis D. Duncan, "Prelaunch Real-Time Impact Prediction System and Research Program for the Athena Rocket," ERDA 202, November 1964.

14. Duncan, Louis D., and Henry Rachele, "Real-Time Meteorological System for Firing Unguided Rockets," J. Appl. Meteor., 6, 2, April 1967.

15. Richart, Harold M., "Basic Requirements for Performing Impact Prediction in the Field," paper presented at the Unguided Rocket Ballistics Conference, University of Texas at El Paso, El Paso, Texas, 30 August - 1 September 1966.

## APPENDIX A

### WIND PROFILES USED FOR AEROBEE 150 TESTS

| ALTITUDE LAYER (FT MSL) | MEAN WIND COMPONENTS (MPH) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | | 2 | | 3 | | 4 | | 5 | |
| | +N-S | +E-W | +N-S | +E-W | +N-S | +E-W | +N-S | +E-W | +N-S | +E-W |
| 4143- 4250 | -2.5 | -3.0 | 6.5 | 9.5 | 4.0 | -17.0 | -0.5 | -18.0 | -4.0 | -1.0 |
| 4250- 4400 | -3.0 | -9.0 | 4.0 | 7.0 | 2.0 | -19.0 | -0.5 | -20.0 | -4.0 | -0.5 |
| 4400- 4600 | -1.5 | -8.0 | 4.0 | 6.0 | 0.5 | -22.0 | 1.5 | -27.5 | -4.5 | -0.5 |
| 4600- 4800 | 1.0 | -7.0 | 11.0 | 4.0 | 0.0 | -23.0 | -0.5 | -27.5 | -7.5 | 0.0 |
| 4800- 5200 | -3.5 | -6.0 | 16.0 | 1.5 | 0.5 | -22.0 | -1.5 | -31.0 | -7.5 | 2.0 |
| 5200- 5600 | -8.0 | -14.0 | 21.5 | -2.5 | 1.5 | -21.0 | 2.5 | -31.0 | -4.0 | 7.5 |
| 5600- 6000 | -2.5 | -18.0 | 23.5 | -3.5 | 2.5 | -22.0 | 4.0 | -35.0 | -4.0 | 12.5 |
| 6000- 6500 | -1.0 | -14.0 | 16.0 | 0.0 | 3.0 | -29.0 | 4.5 | -40.0 | -3.0 | 16.5 |
| 6500- 7000 | -3.0 | -13.0 | 12.0 | 2.0 | 8.0 | -30.5 | 2.5 | -37.0 | -5.5 | 15.5 |
| 7000- 7500 | -5.0 | -6.0 | 10.0 | 0.5 | 8.5 | -31.5 | 2.5 | -35.0 | -8.0 | 13.0 |
| 7500- 8000 | -3.5 | -6.0 | 10.0 | -1.5 | 8.0 | -32.0 | 4.0 | -46.0 | -9.0 | 13.0 |
| 8000- 9000 | -5.8 | -15.0 | 11.5 | 0.0 | 0.0 | -33.4 | 0.0 | -43.8 | 0.0 | 20.7 |
| 9000- 14000 | -16.1 | -9.2 | 3.1 | -2.9 | -6.3 | -37.4 | -15.5 | -43.2 | 8.6 | 7.5 |
| 14000- 19000 | -26.5 | 0.0 | 12.1 | -10.4 | 4.0 | -21.3 | -19.0 | -51.8 | 6.9 | -18.4 |
| 19000- 24000 | -36.9 | -13.2 | 29.4 | -5.2 | 12.1 | -33.4 | -15.5 | -88.1 | 0.0 | -21.9 |
| 24000- 29000 | -41.5 | -34.5 | 56.4 | 9.8 | 0.0 | -56.4 | -18.4 | -105.4 | -13.2 | -35.7 |
| 29000- 34000 | -46.6 | -39.2 | 70.2 | 0.0 | -13.8 | -79.5 | -28.2 | -78.3 | -18.4 | -50.7 |
| 34000- 39000 | -55.3 | -46.6 | 50.1 | -8.6 | -31.1 | -84.1 | -32.8 | -57.0 | -17.8 | -49.5 |
| 39000- 44000 | -68.5 | -57.6 | 34.0 | -19.6 | -26.5 | -73.7 | -43.8 | -51.8 | -15.5 | -43.2 |
| 44000- 49000 | -42.0 | -35.7 | 26.5 | -31.7 | -11.5 | -65.6 | -53.0 | -63.3 | -12.6 | -34.5 |
| 49000- 54000 | -34.5 | -28.8 | 26.5 | -31.7 | -9.8 | -55.9 | -40.3 | -69.7 | -10.4 | -28.8 |
| 54000- 64000 | -16.7 | -9.8 | 10.9 | -19.0 | 23.0 | 0.0 | -36.9 | -21.3 | -12.1 | -6.9 |
| 64000- 74000 | -6.9 | 0.0 | 2.3 | -13.8 | 6.9 | 2.3 | -21.9 | -26.5 | 5.8 | -1.2 |
| 74000- 84000 | -5.2 | 2.9 | 8.1 | -21.8 | 0.0 | 6.9 | -12.1 | -13.8 | 2.9 | -8.1 |
| 84000- 94000 | -8.1 | -4.6 | 2.9 | -32.2 | -9.8 | -3.5 | -12.7 | 0.0 | 9.8 | -8.1 |
| 94000- 104000 | -23.6 | -13.2 | 1.2 | -46.1 | -5.2 | 6.3 | -8.1 | 6.9 | 3.5 | -19.0 |

## APPENDIX B

### WIND PROFILES USED IN ATHENA TESTS

| ALTITUDE LAYER (FT MSL) | MEAN WIND COMPONENTS (MPH) | | | | | |
|---|---|---|---|---|---|---|
| | 1 | | 2 | | 3 | |
| | +N-S | +E-W | +N-S | +E-W | +N-S | +E-W |
| 4493- 4515 | -6.9 | -3.4 | -8.1 | -7.5 | -6.6 | -4.5 |
| 4515- 4549 | -6.2 | -4.1 | -6.6 | -12.1 | -11.6 | -5.4 |
| 4549- 4593 | -5.8 | -5.1 | -8.8 | -10.0 | -17.0 | -2.2 |
| 4593- 4638 | -5.3 | -6.5 | -9.7 | -9.8 | -18.3 | -6.7 |
| 4638- 4702 | -5.0 | -7.5 | -8.4 | -11.1 | -17.4 | -10.5 |
| 4702- 4789 | -4.3 | -8.3 | -11.6 | -10.9 | -18.3 | -12.4 |
| 4789- 4873 | -3.0 | -9.4 | -15.2 | -10.6 | -19.3 | -9.2 |
| 4873- 4968 | -2.5 | -10.8 | -15.7 | -9.5 | -17.2 | -10.5 |
| 4968- 5000 | -1.8 | -11.7 | -14.9 | -12.2 | -16.7 | -8.9 |
| 5000- 5100 | -1.2 | -12.7 | -14.3 | -12.2 | -13.2 | -10.7 |
| 5100- 5200 | -2.2 | -13.5 | -15.6 | -11.6 | -13.5 | -8.5 |
| 5200- 5300 | -2.7 | -14.9 | -17.8 | -11.9 | -12.6 | -10.7 |
| 5300- 5400 | -3.4 | -15.4 | -18.3 | -9.2 | -13.8 | -12.2 |
| 5400- 5500 | -4.2 | -16.5 | -15.5 | -11.2 | -14.3 | -15.9 |
| 5500- 5750 | -5.0 | -17.4 | -16.5 | -13.2 | -17.4 | -13.4 |
| 5750- 6000 | -6.1 | -18.7 | -17.1 | -19.3 | -14.8 | -19.3 |
| 6000- 6250 | -7.2 | -19.8 | -17.1 | -11.0 | -20.0 | -21.7 |
| 6250- 6500 | -8.4 | -20.5 | -19.1 | -11.3 | -19.2 | -20.6 |
| 6500- 7000 | -9.6 | -21.0 | -18.3 | -9.1 | -16.7 | -19.3 |
| 7000- 7500 | -10.3 | -21.2 | -19.0 | -10.9 | -17.5 | -20.9 |
| 7500- 8000 | -10.6 | -21.1 | -19.1 | -9.5 | -14.8 | -19.3 |
| 8000- 8926 | -10.7 | -21.1 | -19.5 | -7.5 | -16.5 | -23.7 |
| 8926-11446 | -11.3 | -20.1 | -19.0 | -1.5 | -16.6 | -21.7 |

APPENDIX B (CONT)

WIND PROFILES USED IN ATHENA TESTS

| ALTITUDE LAYER (FT. MSL) | MEAN WIND COMPONENTS (MPH) | | | | | |
|---|---|---|---|---|---|---|
| | 1 | | 2 | | 3 | |
| | +N-S | +E-W | +N-S | +E-W | +N-S | +E-W |
| 11446- 13446 | -14.6 | -19.6 | -26.0 | 2.9 | -14.8 | -17.8 |
| 13446- 15000 | -18.6 | -20.2 | -6.7 | 15.3 | -18.3 | -21.7 |
| 15000- 17000 | -21.6 | -21.7 | -49.5 | -1.3 | -31.1 | -12.2 |
| 17000- 19000 | -25.7 | -23.0 | -54.1 | -1.4 | -25.5 | -15.6 |
| 19000- 21000 | -29.5 | -23.9 | -66.8 | -1.7 | -27.5 | -16.8 |
| 21000- 23000 | -31.8 | -24.5 | -65.4 | -25.7 | -26.7 | -23.6 |
| 23000- 25000 | -34.5 | -25.0 | -71.8 | -28.3 | -28.5 | -25.2 |
| 25000- 30000 | -33.2 | -41.0 | -72.7 | -44.5 | -22.9 | -28.8 |
| 30000- 35000 | -28.5 | -61.0 | -73.3 | -64.8 | -30.2 | -55.7 |
| 35000- 45000 | -21.5 | -57.0 | -59.5 | -52.6 | -10.6 | -70.6 |
| 45000- 55000 | -1.0 | -42.2 | -20.8 | -26.1 | -6.1 | -41.0 |
| 55000- 65000 | 12.0 | -19.0 | 3.4 | -16.9 | -1.9 | -12.5 |
| 65000- 75000 | 18.8 | -13.2 | 10.2 | 2.1 | 2.7 | -2.2 |
| 75000- 85000 | 17.5 | -11.0 | -0.3 | 12.7 | 2.3 | -11.3 |
| 85000- 95000 | -1.0 | -21.3 | -5.5 | 13.9 | -3.2 | -21.6 |
| 95000-105000 | 0.6 | -28.5 | -5.1 | 12.9 | 6.2 | -30.5 |
| 105000-115000 | 3.5 | -34.5 | -8.4 | 21.4 | 5.6 | -37.6 |
| 115000-135000 | -1.0 | -34.3 | -7.6 | 19.3 | -4.2 | -36.6 |
| 135000-155000 | -3.9 | -19.2 | -14.8 | 37.5 | -3.7 | -25.1 |
| 155000-175000 | -7.5 | 12.0 | -15.6 | 76.7 | -4.1 | 20.3 |
| 175000-195000 | -9.8 | 27.2 | -20.6 | 99.0 | -19.8 | 41.6 |
| 195000-215000 | -8.3 | 23.6 | -20.6 | 101.6 | -4.0 | 16.8 |

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## ATMOSPHERIC SCIENCES RESEARCH PAPERS

1. Webb, W.L., "Development of Droplet Size Distributions in the Atmosphere," June 1954.
2. Hansen, F. V., and H. Rachele, "Wind Structure Analysis and Forecasting Methods for Rockets," June 1954.
3. Webb, W. L., "Net Electrification of Water Droplets at the Earth's Surface," *J. Meteorol.*, December 1954.
4. Mitchell, R., "The Determination of Non-Ballistic Projectile Trajectories," March 1955.
5. Webb, W. L., and A. McPike, "Sound Ranging Technique for Determining the Trajectory of Supersonic Missiles," #1, March 1955.
6. Mitchell, R., and W. L. Webb, "Electromagnetic Radiation through the Atmosphere," #1, April 1955.
7. Webb, W. L., A. McPike, and H. Thompson, "Sound Ranging Technique for Determining the Trajectory of Supersonic Missiles," #2, July 1955.
8. Barichivich, A., "Meteorological Effects on the Refractive Index and Curvature of Microwaves in the Atmosphere," August 1955.
9. Webb, W. L., A. McPike and H. Thompson, "Sound Ranging Technique for Determining the Trajectory of Supersonic Missiles," #3, September 1955.
10. Mitchell, R., "Notes on the Theory of Longitudinal Wave Motion in the Atmosphere," February 1956.
11. Webb, W. L., "Particulate Counts in Natural Clouds," *J. Meteorol.*, April 1956.
12. Webb, W. L., "Wind Effect on the Aerobee," #1, May 1956.
13. Rachele, H., and L. Anderson, "Wind Effect on the Aerobee," #2, August 1956.
14. Beyers, N., "Electromagnetic Radiation through the Atmosphere," #2, January 1957.
15. Hansen, F. V., "Wind Effect on the Aerobee," #3, January 1957
16. Kershner, J., and H. Bear, "Wind Effect on the Aerobee," #4, January 1957.
17. Hoidale, G., "Electromagnetic Radiation through the Atmosphere," #3, February 1957.
18. Querfeld, C. W., "The Index of Refraction of the Atmosphere for 2.2 Micron Radiation," March 1957.
19. White, Lloyd, "Wind Effect on the Aerobee," #5, March 1957.
20. Kershner, J. G., "Development of a Method for Forecasting Component Ballistic Wind," August 1957.
21. Layton, Ivan, "Atmospheric Particle Size Distribution," December 1957.
22. Rachele, Henry and W. H. Hatch, "Wind Effect on the Aerobee," #6, February 1958.
23. Beyers, N. J., "Electromagnetic Radiation through the Atmosphere," #4, March 1958.
24. Prosser, Shirley J., "Electromagnetic Radiation through the Atmosphere," #5, April 1958.
25. Armendariz, M., and P. H. Taft, "Double Theodolite Ballistic Wind Computations," June 1958.
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28. Hoidale, G., "Electromagnetic Propagation through the Atmosphere," #6, February 1959.
29. McLardie, M., R. Helvey, and L. Traylor, "Low-Level Wind Profile Prediction Techniques," #1, June 1959.
30. Lamberth, Roy, "Gustiness at White Sands Missile Range," #1, May 1959.
31. Beyers, N. J., B. Hinds, and G. Hoidale, "Electromagnetic Propagation through the Atmosphere," #7, June 1959.
32. Beyers, N. J., "Radar Refraction at Low Elevation Angles (U)," Proceedings of the Army Science Conference, June 1959.
33. White, L., O. W. Thiele and P. H. Taft, "Summary of Ballistic and Meteorological Support During IGY Operations at Fort Churchill, Canada," August 1959.
34. Hainline, D. A., "Drag Cord-Aerovane Equation Analysis for Computer Application," August 1959.
35. Hoidale, G. B., "Slope-Valley Wind at WSMR," October 1959.
36. Webb, W. L., and K. R. Jenkins, "High Altitude Wind Measurements," *J. Meteorol.*, 16, 5, October 1959.

37. White, Lloyd, "Wind Effect on the Aerobee," #9, October 1959.
38. Webb, W. L., J. W. Coffman, and G. Q. Clark, "A High Altitude Acoustic Sensing System," December 1959.
39. Webb, W. L., and K. R. Jenkins, "Application of Meteorological Rocket Systems," J. Geophys. Res., 64, 11, November 1959.
40. Duncan, Louis, "Wind Effect on the Aerobee," #10, February 1960.
41. Helvey, R. A., "Low-Level Wind Profile Prediction Techniques," #2, February 1960.
42. Webb, W. L., and K. R. Jenkins, "Rocket Sounding of High-Altitude Parameters," *Proc. GM Rel. Symp.*, Dept. of Defense, February 1960.
43. Armendariz, M., and H. H. Monahan, "A Comparison Between the Double Theodolite and Single-Theodolite Wind Measuring Systems," April 1960.
44. Jenkins, K. R., and P. H. Taft, "Weather Elements in the Tularosa Basin," July 1960.
45. Beyers, N. J., "Preliminary Radar Performance Data on Passive Rocket-Borne Wind Sensors," IRE TRANS, MIL ELECT, MIL-4, 2-3, April-July 1960.
46. Webb, W. L., and K. R. Jenkins, "Speed of Sound in the Stratosphere," June 1960.
47. Webb, W. L., K. R. Jenkins, and G. Q. Clark, "Rocket Sounding of High Atmosphere Meteorological Parameters," *IRE Trans. Mil. Elect.*, MIL-4, 2-3, April-July 1960.
48. Helvey, R. A., "Low-Level Wind Profile Prediction Techniques," #3, September 1960.
49. Beyers, N. J., and O. W. Thiele, "Meteorological Wind Sensors," August 1960.
50. Armijo, Larry, "Determination of Trajectories Using Range Data from Three Noncolinear Radar Stations," September 1960.
51. Carnes, Patsy Sue, "Temperature Variations in the First 200 Feet of the Atmosphere in an Arid Region," July 1961.
52. Springer, H. S., and R. O. Olsen, "Launch Noise Distribution of Nike-Zeus Missiles," July 1961.
53. Thiele, O. W., "Density and Pressure Profiles Derived from Meteorological Rocket Measurements," September 1961.
54. Diamond, M. and A. B. Gray, "Accuracy of Missile Sound Ranging," November 1961.
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56. Swanson, R. N., "Low-Level Wind Measurements for Ballistic Missile Application," January 1962.
57. Lamberth, R. L. and J. H. Grace, "Gustiness at White Sands Missile Range," #2, January 1962.
58. Swanson, R. N. and M. M. Hoidale, "Low-Level Wind Profile Prediction Techniques," #4, January 1962.
59. Rachele, Henry, "Surface Wind Model for Unguided Rockets Using Spectrum and Cross Spectrum Techniques," January 1962.
60. Rachele, Henry, "Sound Propagation through a Windy Atmosphere," #2, February 1962.
61. Webb, W. L., and K. R. Jenkins, "Sonic Structure of the Mesosphere," *J. Acous. Soc. Amer.*, 34, 2, February 1962.
62. Tourin, M. H. and M. M. Hoidale, "Low-Level Turbulence Characteristics at White Sands Missile Range," April 1962.
63. Miers, Bruce T., "Mesospheric Wind Reversal over White Sands Missile Range," March 1962.
64. Fisher, E., R. Lee and H. Rachele, "Meteorological Effects on an Acoustic Wave within a Sound Ranging Array," May 1962.
65. Walter, E. L., "Six Variable Ballistic Model for a Rocket," June 1962.
66. Webb, W. L., "Detailed Acoustic Structure Above the Tropopause," *J. Applied Meteorol.*, 1, 2, June 1962.
67. Jenkins, K. R., "Empirical Comparisons of Meteorological Rocket Wind Sensors," *J. Appl. Meteor.*, June 1962.
68. Lamberth, Roy, "Wind Variability Estimates as a Function of Sampling Interval," July 1962.
69. Rachele, Henry, "Surface Wind Sampling Periods for Unguided Rocket Impact Prediction," July 1962.
70 Traylor, Larry, "Coriolis Effects on the Aerobee-Hi Sounding Rocket," August 1962.
71. McCoy, J., and G. Q. Clark, "Meteorological Rocket Thermometry," August 1962.
72. Rachele, Henry, "Real-Time Prelaunch Impact Prediction System," August 1962.

Beyers, N. J., O. W. Thiele, and N. K. Wagner, "Performance Characteristics of Meteorlogical Rocket Wind and Temperature Sensors," October 1962.

Coffman, J., and R. Price, "Some Errors Associated with Acoustical Wind Measurements through a Layer," October 1962.

Armendariz, M., E. Fisher, and J. Serna, "Wind Shear in the Jet Stream at WSMR," November 1962.

76. Armendariz, M., F. Hansen, and S. Carnes, "Wind Variability and its Effect on Rocket Impact Prediction," January 1963.

77. Querfeld, C., and Wayne Yunker, "Pure Rotational Spectrum of Water Vapor, I: Table of Line Parameters," February 1963.

78. Webb, W. L., "Acoustic Component of Turbulence," *J. Applied Meteorol.*, 2, 2, April 1963.

79. Beyers, N. and L. Engberg, "Seasonal Variability in the Upper Atmosphere," May 1963.

80. Williamson, L. E., "Atmospheric Acoustic Structure of the Sub-polar Fall," May 1963.

81. Lamberth, Roy and D. Veith, "Upper Wind Correlations in Southwestern United States," June 1963.

82. Sandlin, E., "An analysis of Wind Shear Differences as Measured by AN/FPS-16 Radar and AN/GMD-1B Rawinsonde," August 1963.

Diamond, M. and R. P. Lee, "Statistical Data on Atmospheric Design Properties Above 30 km," August 1963.

84. Thiele, O. W., "Mesospheric Density Variability Based on Recent Meteorological Rocket Measurements," *J. Applied Meteorol.*, 2, 5, October 1963.

85. Diamond, M., and O. Essenwanger, "Statistical Data on Atmospheric Design Properties to 30 km," *Astro. Aero. Engr.*, December 1963.

86. Hansen, F. V., "Turbulence Characteristics of the First 62 Meters of the Atmosphere," December 1963.

87. Morris, J. E., and B. T. Miers, "Circulation Disturbances Between 25 and 70 kilometers Associated with the Sudden Warming of 1963," *J. of Geophys. Res.*, January 1964.

88. Thiele, O. W., "Some Observed Short Term and Diurnal Variations of Stratospheric Density Above 30 km," January 1964.

89. Sandlin, R. E., Jr. and E. Armijo, "An Analysis of AN/FPS-16 Radar and AN/GMD-1B Rawinsonde Data Differences," January 1964.

90. Miers, B. T., and N. J. Beyers, "Rocketsonde Wind and Temperature Measurements Between 30 and 70 km for Selected Stations," *J. Applied Meteorol.*, February 1964.

91. Webb, W. L., "The Dynamic Stratosphere," *Astronautics and Aerospace Engineering*, March 1964.

92. Low, R. D. H., "Acoustic Measurements of Wind through a Layer," March 1964.

93. Diamond. M., "Cross Wind Effect on Sound Propagation," *J. Applied Meteorol.*, April 1964.

94. Lee, R. P., "Acoustic Ray Tracing," April 1964.

95. Reynolds, R. D., "Investigation of the Effect of Lapse Rate on Balloon Ascent Rate," May 1964.

96. Webb, W. L., "Scale of Stratospheric Detail Structure," *Space Research V*, May 1964.

97. Barber, T. L., "Proposed X-Ray-Infrared Method for Identification of Atmospheric Mineral Dust," June 1964.

98. Thiele, O. W., "Ballistic Procedures for Unguided Rocket Studies of Nuclear Environments (U)," Proceedings of the Army Science Conference, June 1964.

99. Horn, J. D., and E. J. Trawle, "Orographic Effects on Wind Variability," July 1964.

100. Hoidale, G., C. Querfeld, T. Hall, and R. Mireles, "Spectral Transmissivity of the Earth's Atmosphere in the 250 to 500 Wave Number Interval," #1, September 1964.

101. Duncan, L. D., R. Ensey, and B. Engebos, "Athena Launch Angle Determination," September 1964.

102. Thiele, O. W., "Feasibility Experiment for Measuring Atmospheric Density Through the Altitude Range of 60 to 100 KM Over White Sands Missile Range," October 1964.

103. Duncan, L. D., and R. Ensey, "Six-Degree-of-Freedom Digital Simulation Model for Unguided, Fin-Stabilized Rockets," November 1964.

104. Hoidale, G., C. Querfeld, T. Hall, and R. Mireles, "Spectral Transmissivity of the Earth's Atmosphere in the 250 to 500 Wave Number Interval," #2, November 1964.

105. Webb, W. L., "Stratospheric Solar Response," *J. Atmos. Sci.*, November 1964.

106. McCoy, J. and G. Clark, "Rocketsonde Measurement of Stratospheric Temperature," December 1964.

107. Farone, W. A., "Electromagnetic Scattering from Radially Inhomogeneous Spheres as Applied to the Problem of Clear Atmosphere Radar Echoes," December 1964.

108. Farone, W. A., "The Effect of the Solid Angle of Illumination or Observation on the Color Spectra of 'White Light' Scattered by Cylinders," January 1965.

109. Williamson, L. E., "Seasonal and Regional Characteristics of Acoustic Atmospheres," *J. Geophys. Res.*, January 1965.

110. Armendariz, M., "Ballistic Wind Variability at Green River, Utah," January 1965.

111. Low, R. D. H., "Sound Speed Variability Due to Atmospheric Composition," January 1965.

112. Querfeld, C. W., 'Mie Atmospheric Optics," *J. Opt. Soc. Amer.*, January 1965.

113. Coffman, J., "A Measurement of the Effect of Atmospheric Turbulence on the Coherent Properties of a Sound Wave," January 1965.

114. Rachele, H., and D. Veith, "Surface Wind Sampling for Unguided Rocket Impact Prediction," January 1965.

115. Ballard, H., and M. Izquierdo, "Reduction of Microphone Wind Noise by the Generation of a Proper Turbulent Flow," February 1965.

116. Mireles, R., "An Algorithm for Computing Half Widths of Overlapping Lines on Experimental Spectra," February 1965.

117. Richart, H., "Inaccuracies of the Single-Theodolite Wind Measuring System in Ballistic Application," February 1965.

118. D'Arcy, M., "Theoretical and Practical Study of Aerobee-150 Ballistics," March 1965.

119. McCoy, J., "Improved Method for the Reduction of Rocketsonde Temperature Data," March 1965.

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122. Farone, W. A., and C. Querfeld, "Electromagnetic Scattering from an Infinite Circular Cylinder at Oblique Incidence," April 1965.

123. Rachele, H., "Sound Propagation through a Windy Atmosphere," April 1965.

124. Miers, B., "Upper Stratospheric Circulation over Ascension Island," April 1965.

125. Rider, L., and M. Armendariz, " A Comparison of Pibal and Tower Wind Measurements," April 1965.

126. Hoidale, G. B., "Meteorological Conditions Allowing a Rare Observation of 24 Micron Solar Radiation Near Sea Level," *Meteorol. Magazine*, May 1965.

127. Beyers, N. J., and B. T. Miers, "Diurnal Temperature Change in the Atmosphere Between 30 and 60 km over White Sands Missile Range," *J. Atmos. Sci.*, May 1965.

128. Querfeld, C., and W. A. Farone, "Tables of the Mie Forward Lobe," May 1965.

129. Farone, W. A., Generalization of Rayleigh-Gans Scattering from Radially Inhomogeneous Spheres," *J. Opt. Soc. Amer.*, June 1965.

130. Diamond, M., "Note on Mesospheric Winds Above White Sands Missile Range," *J. Applied Meteorol.*, June 1965.

131. Clark, G. Q., and J. G. McCoy, "Measurement of Stratospheric Temperature," *J. Applied Meteorol.*, June 1965.

132. Hall, T., G. Hoidale, R. Mireles, and C. Querfeld, "Spectral Transmissivity of the Earth's Atmosphere in the 250 to 500 Wave Number Interval," #3, July 1965.

133. McCoy, J., and C. Tate, "The Delta-T Meteorological Rocket Payload," June 1964.

134. Horn, J. D., "Obstacle Influence in a Wind Tunnel," July 1965.

135. McCoy, J., "An AC Probe for the Measurement of Electron Density and Collision Frequency in the Lower Ionosphere," July 1965.

136. Miers, B. T., M. D. Kays, O. W. Thiele and E. M. Newby, "Investigation of Short Term Variations of Several Atmospheric Parameters Above 30 KM," July 1965.

137. Serna, J., "An Acoustic Ray Tracing Method for Digital Computation," September 1965.
138. Webb, W. L., "Morphology of Noctilucent Clouds," *J. Geophys. Res.*, 70, 18, 4463-4475, September 1965.
139. Kays, M., and R. A. Craig, "On the Order of Magnitude of Large-Scale Vertical Motions in the Upper Stratosphere," *J. Geophys. Res.*, 70, 18, 4453-4462, September 1965.
140. Rider, L., "Low-Level Jet at White Sands Missile Range," September 1965.
141. Lamberth, R. L., R. Reynolds, and Morton Wurtele, "The Mountain Lee Wave at White Sands Missile Range," *Bull. Amer. Meteorol. Soc.*, 46, 10, October 1965.
142. Reynolds, R. and R. L. Lamberth, "Ambient Temperature Measurements from Radiosondes Flown on Constant-Level Balloons," October 1965.
143. McCluney, E., "Theoretical Trajectory Performance of the Five-Inch Gun Probe System," October 1965.
144. Pena, R. and M. Diamond, "Atmospheric Sound Propagation near the Earth's Surface," October 1965.
145. Mason, J. B., "A Study of the Feasibility of Using Radar Chaff For Stratospheric Temperature Measurements," November 1965.
146. Diamond, M., and R. P. Lee, "Long-Range Atmospheric Sound Propagation," *J. Geophys. Res.*, 70, 22, November 1965.
147. Lamberth, R. L., "On the Measurement of Dust Devil Parameters," November 1965.
148. Hansen, F. V., and P. S. Hansen, "Formation of an Internal Boundary over Heterogeneous Terrain," November 1965.
149. Webb, W. L., "Mechanics of Stratospheric Seasonal Reversals," November 1965.
150. U. S. Army Electronics R & D Activity, "U. S. Army Participation in the Meteorological Rocket Network," January 1966.
151. Rider, L. J., and M. Armendariz, "Low-Level Jet Winds at Green River, Utah," February 1966.
152. Webb, W. L., "Diurnal Variations in the Stratospheric Circulation," February 1966.
153. Beyers, N. J., B. T. Miers, and R. J. Reed, "Diurnal Tidal Motions near the Stratopause During 48 Hours at WSMR," February 1966.
154. Webb, W. L., "The Stratospheric Tidal Jet," February 1966.
155. Hall, J. T., "Focal Properties of a Plane Grating in a Convergent Beam," February 1966.
156. Duncan, L. D., and Henry Rachele, "Real-Time Meteorological System for Firing of Unguided Rockets," February 1966.
157. Kays, M. D., "A Note on the Comparison of Rocket and Estimated Geostrophic Winds at the 10-mb Level," *J. Appl. Meteor.*, February 1966.
158. Rider, L., and M. Armendariz, " A Comparison of Pibal and Tower Wind Measurements," *J. Appl. Meteor.*, 5, February 1966.
159. Duncan, L. D., "Coordinate Transformations in Trajectory Simulations," February 1966.
160. Williamson, L. E., "Gun-Launched Vertical Probes at White Sands Missile Range," February 1966.
161. Randhawa, J. S., Ozone Measurements with Rocket-Borne Ozonesondes," March 1966.
162. Armendariz, Manuel, and Laurence J. Rider, "Wind Shear for Small Thickness Layers," March 1966.
163. Low, R. D. H., "Continuous Determination of the Average Sound Velocity over an Arbitrary Path," March 1966.
164. Hansen, Frank V., "Richardson Number Tables for the Surface Boundary Layer," March 1966.
165. Cochran, V. C., E. M. D'Arcy, and Florencio Ramirez, "Digital Computer Program for Five-Degree-of-Freedom Trajectory," March 1966.
166. Thiele, O. W., and N. J. Beyers, "Comparison of Rocketsonde and Radiosonde Temperatures and a Verification of Computed Rocketsonde Pressure and Density," April 1966.
167. Thiele, O. W., "Observed Diurnal Oscillations of Pressure and Density in the Upper Stratosphere and Lower Mesosphere," April 1966.
168. Kays, M. D., and R. A. Craig, "On the Order of Magnitude of Large-Scale Vertical Motions in the Upper Stratosphere," *J. Geophy. Res.*, April 1966.
169. Hansen, F. V., "The Richardson Number in the Planetary Boundary Layer," May 1966.

170. Ballard, H. N., "The Measurement of Temperature in the Stratosphere and Mesosphere," June 1966.
171. Hansen, Frank V., "The Ratio of the Exchange Coefficients for Heat and Momentum in a Homogeneous, Thermally Stratified Atmosphere," June 1966.
172. Hansen, Frank V., "Comparison of Nine Profile Models for the Diabatic Boundary Layer," June 1966.
173. Rachele, Henry, "A Sound-Ranging Technique for Locating Supersonic Missiles," May 1966.
174. Farone, W. A., and C. W. Querfeld, "Electromagnetic Scattering from Inhomogeneous Infinite Cylinders at Oblique Incidence," *J. Opt. Soc. Amer.* 56, 4, 476-480, April 1966.
175. Mireles, Ramon, "Determination of Parameters in Absorption Spectra by Numerical Minimization Techniques," *J. Opt. Soc. Amer.* 56, 5, 644-647, May 1966.
176. Reynolds, R., and R. L. Lamberth, "Ambient Temperature Measurements from Radiosondes Flown on Constant-Level Balloons," *J. Appl. Meteorol.*, 5, 3, 304-307, June 1966.
177. Hall, James T., "Focal Properties of a Plane Grating in a Convergent Beam," *Appl. Opt.*, 5, 1051, June 1966
178. Rider, Laurence J., "Low-Level Jet at White Sands Missile Range," *J. Appl. Meteorol.*, 5, 3, 283-287, June 1966.
179. McCluney, Eugene, "Projectile Dispersion as Caused by Barrel Displacement in the 5-Inch Gun Probe System," July 1966.
180. Armendariz, Manuel, and Laurence J. Rider, "Wind Shear Calculations for Small Shear Layers," June 1966.
181. Lamberth, Roy L., and Manuel Armendariz, "Upper Wind Correlations in the Central Rocky Mountains," June 1966.
182. Hansen, Frank V., and Virgil D. Lang, "The Wind Regime in the First 62 Meters of the Atmosphere," June 1966.
183. Randhawa, Jagir S., "Rocket-Borne Ozonesonde," July 1966.
184. Rachele, Henry, and L. D. Duncan, "The Desirability of Using a Fast Sampling Rate for Computing Wind Velocity from Pilot-Balloon Data," July 1966.
185. Hinds, B. D., and R. G. Pappas, "A Comparison of Three Methods for the Correction of Radar Elevation Angle Refraction Errors," August 1966.
186. Riedmuller, G. F., and T. L. Barber, "A Mineral Transition in Atmospheric Dust Transport," August 1966.
187. Hall, J. T., C. W. Querfeld, and G. B. Hoidale, "Spectral Transmissivity of the Earth's Atmosphere in the 250 to 500 Wave Number Interval," Part IV (Final), July 1966.
188. Duncan, L. D. and B. F. Engebos, "Techniques for Computing Launcher Settings for Unguided Rockets," September 1966.
189. Duncan, L. D., "Basic Considerations in the Development of an Unguided Rocket Trajectory Simulation Model," September 1966.
190. Miller, Walter B., "Consideration of Some Problems in Curve Fitting," September 1966.
191. Cermak, J. E., and J. D. Horn, "The Tower Shadow Effect," August 1966.
192. Webb, W. L., "Stratospheric Circulation Response to a Solar Eclipse," October 1966.
193. Kennedy, Bruce, "Muzzle Velocity Measurement," October 1966.
194. Traylor, Larry E., "A Refinement Technique for Unguided Rocket Drag Coefficients," October 1966
195. Nusbaum, Henry, "A Reagent for the Simultaneous Microscope Determination of Quartz and Halides," October 1966.
196. Kays, Marvin and R. O. Olsen, "Improved Rocketsonde Parachute-derived Wind Profiles," October 1966.
197. Engebos, Bernard F. and Duncan, Louis D., "A Nomogram for Field Determination of Launcher Angles for Unguided Rockets," October 1966.
198. Webb, W. L., "Midlatitude Clouds in the Upper Atmosphere," November 1966.
199. Hansen, Frank V., "The Lateral Intensity of Turbulence as a Function of Stability," November 1966.
200. Rider, L. J. and M. Armendariz, "Differences of Tower and Pibal Wind Profiles," November 1966.
201. Lee, Robert P., "A Comparison of Eight Mathematical Models for Atmospheric Acoustical Ray Tracing," November 1966.
202. Low, R. D. H., et al., "Acoustical and Meteorological Data Report SOTRAN I and II," November 1966.

203. Han[illegible] Balance," December 1966.

204. Armendariz, M., and H. Rachele, "Determination of a Representative Wind Profile from Balloon Data," December 1966.

205. Hansen, Frank V., "The Aerodynamic Roughness of the Complex Terrain of White Sands Missile Range," January 1967.

206. Morris, James E., "Wind Measurements in the Subpolar Mesopause Region," January 1967.

207. Hall, James T., "Attenuation of Millimeter Wavelength Radiation by Gaseous Water," January 1967.

208. Thiele, O. W., and N. J. Beyers, "Upper Atmosphere Pressure Measurements With Thermal Conductivity Gauges," January 1967.

209. Armendariz, M., and H. Rachele, "Determination of a Representative Wind Profile from Balloon Data," January 1967.

210. Hansen, F. V., "The Aerodynamic Roughness of the Complex Terrain of White Sands Missile Range, New Mexico," January 1967.

211. D'Arcy, Edward M., "Some Applications of Wind to Unguided Rocket Impact Prediction," March 1967.

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13. ABSTRACT

An accurate and rapid wind compensation technique for the field determination of launcher settings for unguided rockets is presented. The method was tested with a five-degree-of-freedom trajectory simulation program using several observed wind profiles. The results of five computer tests for an Aerobee 150 show that the maximum theoretical impact miss was 3.8 statute miles when the theoretical impact displacement was 147.4 statute miles. In three tests for an Athena (two-stage), the maximum theoretical impact miss was 5.4 statute miles when the theoretical impact displacement due to the wind was 141.8 statute miles.

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