Rocket Vehicle Targeting for the PLACES Ionospheric Plasma Test Series

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The PLACES (Position Location and Communication Effects Simulations) test program, conducted in December 1980 at Elgin Gulf Test Range, involved a series of ionospheric releases of barium/barium-nitrate vapor. The program investigated effects of a structured ionospheric plasma (similar to that produced by a high-altitude nuclear detonation) on satellite rf links and provided in situ measurement of the plasma structure. Terrier-Tomahawk rocket systems boosted the barium carrier payloads, beacon payloads (plasma occultation experiment), and probe payloads (plasma in situ measurement). Drifting plasma tracking procedures, beacon- and probe-vehicle targeting procedures, and vehicle flight test results are presented.

Introduction

THE PLACES (Position Location and Communication Effects Simulations) program culminated in the field experiment conducted in December 1980 at the Eglin Air Force Base Gulf Test Range, Florida. The program investigated the effects of a structured ionospheric plasma on communication and navigation satellite rf links and provided in situ measurement of the plasma structure. The plasma environment was produced by the release of 48 kg of barium/barium-nitrate vapor at an altitude of 185 km (four separate releases on different evenings). An airborne receiving station received signals from a communications satellite through the drifting structured-plasma cloud. Rocket-borne transmitters were flown (on beacon rocket vehicles) behind the drifting plasma as seen by fixed ground-receiving stations. A rocket-borne payload carried diagnostic instruments through the structured plasma (probe rocket vehicle).

Barium-plasma clouds simulate many aspects of plasmas that are produced by high-altitude nuclear detonations. This simulation technique was developed and used during Project SECEDE II (Ref. 1) which was conducted in January 1971. The most recent previous barium release program (Project STRESS)[2] was also conducted at Eglin (February 1977). STRESS, like PLACES, investigated satellite rf signal propagation under disturbed conditions.

The Terrier-Tomahawk 9 (TT9) (9-in., 22.9-cm-diam payload) rocket booster system was selected for all payloads because of the mass range of the payloads (106-142 kg) and because of the required range-altitude performance envelope (to allow for a wide variation of possible distances and directions of plasma cloud drift). The plasma structure had to develop prior to the targeting and firing of the beacon and probe rocket vehicles. The cloud-drift direction and speed during development were not known a priori. Therefore these companion instrumentation vehicles had to have a large performance envelope.

A field computational procedure for targeting and aiming the companion instrumentation rocket systems included:

1) Processing and smoothing the real-time, raw data from the track of the moving, developing, structured-plasma cloud (data from TV trackers).

2) Predicting the cloud position at times that corresponded to beacon and probe payload arrival times at the corresponding target points (cloud position for the probe and a point 100 km behind the cloud as seen by the beacon-receiver ground stations for the beacon).

3) Simulating the actual vehicle trajectories and, through an iterative computational process, determining the required launch angles (elevation and azimuth) of each companion vehicle to hit the predicted target point.

4) Processing wind tower and wind balloon tracking data to produce an atmospheric wind profile that was updated continuously.

5) Determining corrected launch angles of each rocket vehicle based on the nominal launch angles (see item 3 above) and the current atmospheric wind profile prior to setting the launcher and the booster firing.

The above procedure was implemented on a network of three minicomputers (installed in a computer trailer located near the launch site).

This article emphasizes the structured ion cloud tracking and vehicle targeting computational procedure. The actual operation of this procedure, based on the real-time cloud tracking, is discussed with a presentation of some actual cloud-tracking and vehicle-targeting data. The performance and ballistic accuracy of the rocket systems is also presented.

Test Range Facilities and Instrumentation

The Eglin AFB Gulf Test Range, Florida (Fig. 1), was selected for the PLACES test series.

The launch site was located at Area A-15A on Santa Rosa Island. Two rocket launchers (one single-boom and one twin-boom) were located at this site.

Rocket vehicle trajectory tracking was provided by C-band FPS-16 radars (three located at Eglin AFB Area A-20, and one at Area D-3). Payload telemetry was received at the Eglin AFB Area B-4 telemetry facility. Range control was conducted at the Central Control Facility (CCF). Launch and vehicle control were conducted at the launch site.

Rocket Vehicle Payloads

Ten rocket systems were planned for launch during the PLACES test series. These included four with barium-release payloads, four beacon vehicles for cloud occultation experiments, and two probe vehicles for cloud-penetration experiments.

The rocket booster system was the Terrier-Tomahawk 9 (TT9) to allow for the various payloads (mass variation 106-

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Presented as Paper 82-1723 at the AIAA 6th Sounding Rocket Conference, Orlando, Fla., Oct. 26-28, 1982; submitted Nov. 5, 1982; revision received June 6, 1983.

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142 kg) and the performance envelopes required for the beacon and probe vehicles.

The barium-release payloads had a total mass of 142 kg (including 48 kg of $Ba/BaNO_3$) and a total length of 2.489 m. The beacon payloads had a total mass of 105.7 kg and a total length of 2.667 m. The probe payloads had a total mass of 106.6 kg and a total length of 2.896 m. The cylindrical diameter of all of the payloads was 9 in. (22.9 cm); the nose shape of all of the payloads was a spherically blunted fineness-ratio 3.0 ogive. The spherical nose radius was 0.95 cm for the barium carrier and probe payloads and 1.27 cm for the beacon payloads.

Barium Releases and Expected Ion Cloud Track

Four separate barium releases (an explosively dispersed mixture of barium and barium nitrate) were planned for the PLACES test series on different evenings at 185 km altitude. The four events were named GAIL, HOPE, IRIS, and JAN.

The release position for Event GAIL was planned for 29.37°N latitude and 87.37°W longitude. The release time was planned for 5 min before 6 deg of solar depression angle (SDA). The release position was based primarily on range safety considerations of potential beacon and probe payload impact points. The trajectories of these companion payloads were dependent on the position of the fully developed structured plasma cloud. A cloud drift direction variation from 70°T to 146°T azimuth and drift-distance variation from 40 to 100 km (as the striated plasma moves and develops to the size and structure of interest) was considered possible (Fig. 1).

The range safety limits of allowable firing azimuths on the Eglin Range are 140°T and 210°T. The extreme west and east possible positions of a developed cloud caused the respective firing azimuths of the beacon vehicle (which had to pass to the west of the plasma striations) and the probe vehicle (which had to pass through the striations) to be near these respective range safety limits. The planned Event GAIL release position and the related annulus-section plan area of possible developed ion cloud locations allowed a reasonable amount of trajectory dispersion while still obtaining occultation of the beacon vehicle by the plasma structure as seen from the beacon-receiver sites on Cape San Blas (Elgin Site D-3) and St. George Island (Fig. 1). This allowed dispersion was approximately 2σ for the most likely drift of 90°T to 110°T azimuth and 1σ for cloud positions along the extreme expected directions of 70°T and 146°T. The dimensions of the structured ion cloud model used for the occultation/dispersion study was 20 km (along the magnetic field—dip of 60 deg and declination 1 deg) by 6 km (east-west) by 3 km (in the vertical plane).

The planned Event GAIL release time provided the optimum combination of sunlight on the ion cloud and dark sky background to enhance optical tracking and photography at the time the cloud was predicted to be most sharply striated (approximately release $R+20$ min). It was expected that both the release time and the release coordinates for subsequent barium events could change after a field analysis of the Event GAIL plasma cloud behavior.

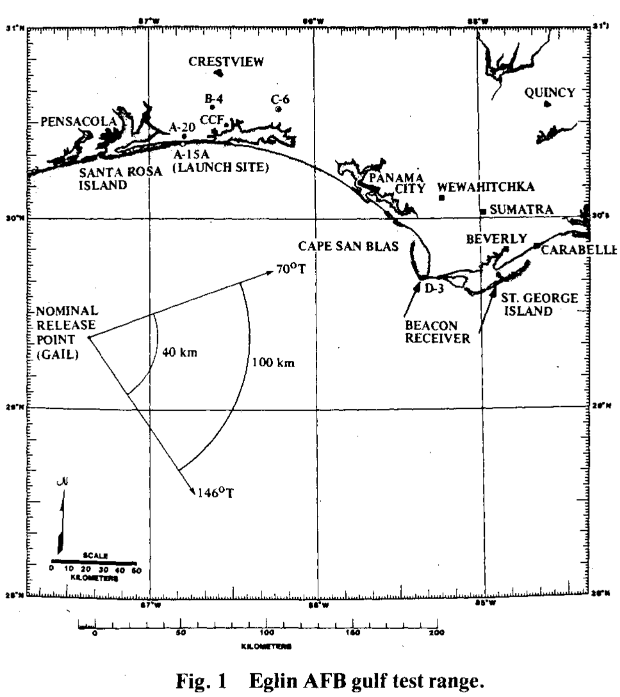

Fig. 1 Eglin AFB gulf test range.

PLACES Geometry Master Coordinate System

A master coordinate system was used to locate the various ground-based instrumentation sites, the barium ion cloud track, the target points, and the required nominal trajectories for the various rocket vehicles. This master reference system had its origin at the launch site. The coordinate system was an orthogonal, tangent-plane system with X (south), Y (east), and Z (local vertical). This system is shown in Fig. 2.

Barium Ion Cloud Tracking

The region of interest for the PLACES experiments was the striated or structured portion of the ion cloud. A pair of optical or TV trackers followed the region of sharp striations from different geographic locations to provide the source of ion cloud location data.

One TV tracker was located near one of the beacon-receiver sites (Cape San Blas, Fig. 1); it provided a line from that location to the point of interest on the structured ion cloud to be used for beacon-vehicle targeting. This look-line was established by the TV tracker azimuth and elevation and the tracker location. This approach was followed since this TV tracker (which was designated the "beacon TV tracker") saw the cloud as the beacon receivers saw the cloud during the subsequent beacon vehicle occultation (illustrated in Fig. 2).

A similar approach was taken with the other TV tracker. It was designated the launcher or probe TV tracker since it was located near the launch site (within 400 m) and since the optical view from the launch site to the cloud was essentially in the plane of the probe payload trajectory as the vehicle flew directly to the cloud.

Beacon Vehicles

The first step in the computation of the cloud location, as seen from the beacon TV tracker, was to determine the direction cosines or components of a unit vector along the TV-tracker look-line referenced to the master coordinate system.

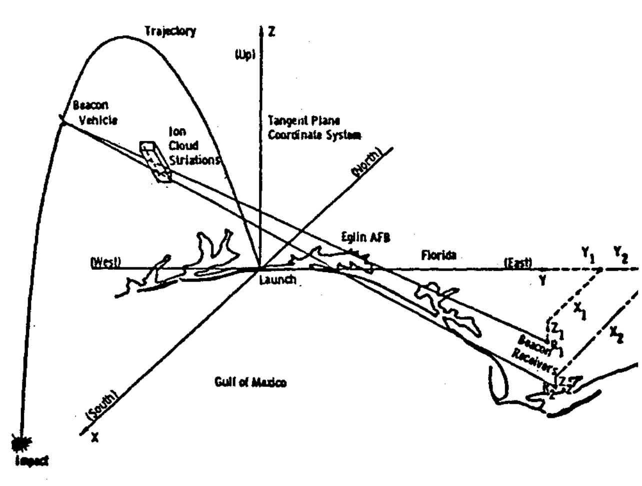

Fig. 2 General occultation geometry for PLACES beacon vehicle.

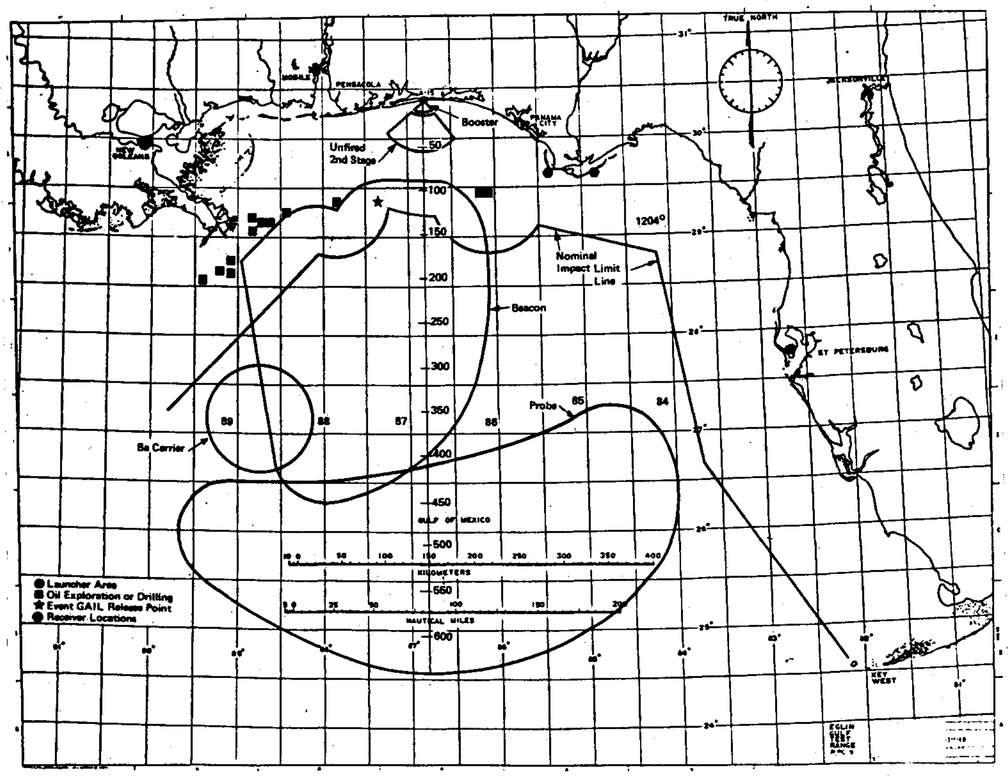

Fig. 3 **PLACES vehicle impact areas (3σ).**

The local direction cosines (generated from the azimuth and elevation data from the TV tracker) were converted into the master system using the latitude and longitude of the launch site and TV tracker. These direction cosines ($\cos\theta_{XB}$, θ_{YB}, θ_{ZB}) and the location of the beacon TV-tracker X_{BT}, Y_{BT}, Z_{BT} established the location of the beacon TV-tracker look-line in the master coordinate system. There were two ways to establish a point on this line that corresponds to the cloud location by intersecting this line with different planes. A "quality" priority for the approaches was established during the planning of the test series. The techniques are discussed below in order of their priority (X_{CB}, Y_{CB}, Z_{CB} is the ion cloud location in the master coordinate system established along the beacon TV-tracker look-line).

1) The first priority computation involved combining the beacon TV-tracker data with that from the TV tracker located near the launch area. The plane, which intersects the beacon TV-tracker look-line so as to establish X_{CB}, Y_{CB}, Z_{CB} in this case, was the master coordinate system azimuthal plane that contained the look-line from the launcher TV tracker. The look-line from this tracker is aligned with the most densely striated region of the barium ion cloud as seen from this location. The azimuth and elevation angles of this TV tracker (assumed to be referenced to the master coordinate system) were designated as AZ_{LT} and θ_{LT}. The computational equations that were applied to establish the cloud location with this approach are:

$$X_{CB} = \frac{X_{BT}\cos\theta_{YB} - Y_{BT}\cos\theta_{XB}}{(\tan AZ_{LT})\cos\theta_{XB} + \cos\theta_{YB}}$$

$$Y_{CB} = \frac{\tan AZ_{LT}(Y_{BT}\cos\theta_{XB} - X_{BT}\cos\theta_{YB})}{(\tan AZ_{LT})\cos\theta_{XB} + \cos\theta_{YB}}$$

$$Z_{CB} = [\tan AZ_{LT}(Z_{BT}\cos\theta_{XB} - X_{BT}\cos\theta_{ZB}) + Z_{BT}\cos\theta_{YB}$$
$$- Y_{BT}\cos\theta]_{ZB} / [(\tan AZ_{LT})\cos\theta_{XB} + \cos\theta_{YB}]$$

2) The second priority X_{CB}, Y_{CB}, Z_{CB} computation involved intersecting the beacon TV-tracker look-line with a Z plane (Z_E) that was determined with an empirical cloud-height variation based on a previous (Project STRESS) cloud tracking data set. The variation was applied to the barium carrier vehicle-Z position at the nominal time of barium release as determined from the vehicle radar track. The cloud-Z position (Z_{CB}) is thus determined and the equations that were applied to establish the cloud location with this approach are:

$$Z_{CB} = Z_E$$

$$D_{BTC} = (Z_E - Z_{BT}) / \cos\theta_{ZB}$$

$$X_{CB} = X_{BT} + D_{BTC}\cos\theta_{XB}$$

$$Y_{CB} = Y_{BT} + D_{BTC}\cos\theta_{YB}$$

where D_{BTC} is the distance from the beacon TV tracker to the Z plane, which is at the empirical height.

Probe Vehicles

The probe vehicles were to pass directly through the most densely striated region of the barium ion cloud on the upleg of the vehicle trajectory. Since the TV tracker located near the launch pads viewed the ion cloud in the plane of the vehicle trajectory, this tracker was considered to be the source of data for probe vehicle targeting. Again, two approaches were applied to determine the actual cloud position along this TV tracker look-line. Each of these involved the intersecting of the look-line with a plane.

The priority of these approaches for cloud-position determination for the probe vehicles was the same as that for the beacon vehicles. The first priority approach intersected the look-line with a master coordinate system vertical plane that contained the beacon TV-tracker location and the beacon TV-tracker look-line to the cloud. The second priority is implemented with the Z plane as determined by the empirical Z variation (Z_E).

The direction cosines of the probe TV-tracker look-line were computed directly since the pointing data were already in the launcher coordinate system:

$$\cos\theta_{XP} = -\cos EL_{PT}\cos AZ_{PT}$$

$$\cos\theta_{YP} = \cos EL_{PT}\sin AZ_{PT}$$

$$\cos\theta_{ZP} = \sin EL_{PT}$$

The computation techniques are described below in order of their priority.

1) The probe TV-tracker look-line data were combined with the beacon TV-tracker look-angles in the master coordinate system to determine the cloud location for probe targeting:

$$X_{CP} = \frac{(X_{BT}\tan AZ'_{BT} + Y_{BT})\cos\theta_{XP}}{(\tan AZ'_{BT})\cos\theta_{XP} + \cos\theta_{YP}}$$

$$Y_{CP} = \frac{(X_{BT}\tan AZ'_{BT} + Y_{BT})\cos\theta_{YP}}{(\tan AZ'_{BT})\cos\theta_{XP} + \cos\theta_{YP}}$$

$$Z_{CP} = \frac{(X_{BT}\tan AZ'_{BT} + Y_{BT})\cos\theta_{ZP}}{(\tan AZ'_{BT})\cos\theta_{XP} + \cos\theta_{YP}}$$

where

$$AZ'_{BT} = \cos^{-1}\left(\frac{\cos\theta_{XB}}{\cos EL'_{BT}}\right)$$

and

$$EL'_{BT} = \sin^{-1}(\cos\theta_{ZB})$$

2) The direction cosines of the probe TV-tracker look-line to the cloud were combined with the empirical height to determine the cloud location for probe targeting as follows:

$$X_{CP} = D_{PTC}\cos\theta_{XP}$$

$$Y_{CP} = D_{PTC}\cos\theta_{YP}$$

$$Z_{CP} = Z_E$$

where

$$D_{PTC} = \frac{Z_E}{\cos\theta_{ZP}}$$

Rocket Vehicle Targeting

Barium Vehicles

The barium rocket vehicles were targeted for release at an altitude of 185 km at the planned coordinates and on the upleg portion of the trajectory. The required launch time was determined by subtracting the vehicle time of flight to the target from the time of 6 deg SDA – 5 min. This time was then rounded to the next even minute to determine the actual vehicle launch time.

Beacon Vehicles

The companion vehicle targeting procedures were based on a continuous minicomputer processing of TV tracking and empirical Z data. The X_{CB}, Y_{CB}, Z_{CB} or X_{CP}, Y_{CP}, Z_{CP} were computed using all approaches; each position data set was fitted with a linear least-squares procedure with time as the independent variable. The smoothing period could be varied from 2 to 6 min in 30-s increments for all computation approaches. The fitting procedure was updated each time a new tracking data point was read, regardless of the source. These targeting computations are described completely in Ref. 3.

The beacon rocket vehicles were targeted, based on the track of the structured ion cloud; specifically, on the predicted cloud position at the expected time of beacon vehicle occultation as seen by the beacon receiver sites. The smoothed position rate of change (velocity) data was combined with a time offset to produce this predicted cloud position. The offset time included:

1) Computation time to determine the required nominal launch angles needed to hit the target.
2) Computation time required to correct the nominal launch angles for atmospheric wind effects to determine actual launch angles.
3) Computation time to predict the payload and booster impact points.
4) Time for the Eglin Range Safety Group to determine a "go" or "no go" range.
5) Time for setting the launcher.
6) Short terminal count to first-stage booster firing.
7) Time of flight of the beacon vehicle to the target.

The required offset time for the beacon vehicles was 11 min (flight time accounted for approximately 7 min of this time). The beacon-vehicle occultation had to be on the downleg (after vehicle apogee) because the crossing angle of the vehicle flight path and the Earth magnetic-field lines (dip of 60 deg) along which the ion cloud striations were aligned had to be 25 deg or greater. Such a condition would not be achieved with an upleg occulation.

Once the predicted cloud position at the beacon vehicle target-intercept time was determined, the beacon vehicle-target position could be found. The beacon was to pass behind the barium ion cloud as seen by the beacon receivers at a given distance (D_{CT}) from the cloud. The actual target point was computed using the predicted cloud position (X_{CBP}, Y_{CBP}, Z_{CBP}) and the point midway between the two beacon receivers (X_{RA}, Y_{RA}, Z_{RA} – for beacon receiver average). The line between these two points was extended the distance (D_{CT}) behind the cloud to determine the beacon vehicle target.

Term definition and a summary of the computational equations applied as described above for finding the beacon vehicle target follow.

X_{TB}, Y_{TB}, Z_{TB} = beacon vehicle target position

D_{CT} = distance from cloud to target point (set at 100 km during test series planning)

D_{RAC} = distance from beacon receiver average point to the predicted cloud position

$$D_{RAC} = \sqrt{(X_{CBP}-X_{RA})^2 + (Y_{CBP}-Y_{RA})^2 + (Z_{CBP}-Z_{RA})^2}$$

The target position is

$$X_{TB} = X_{CBP} + D_{CT}(X_{CBP} - X_{RA}/D_{RAC})$$

$$Y_{TB} = Y_{CBP} + D_{CT}(Y_{CBP} - Y_{RA}/D_{RAC})$$

$$Z_{TB} = Z_{CBP} + D_{CT}(Z_{CBP} - Z_{RA}/D_{RAC})$$

Probe Vehicles

The probe rockets were targeted in a similar manner with the exceptions of the target point being the actual predicted cloud position, the look-line source being the probe TV tracker, and the offset time of 6 min to reflect the decreased time of flight of the probe payload to the target (2.5 min). The pentration of the ion cloud structure by the probe payload was planned for the upleg.

The launch time for either a beacon or a probe was determined to the nearest second and not rounded for the actual launch. The time at the target for either type vehicle was fixed by the respective offset times added to the time at which the targeting sequence was begun. The respective launch times were then determined by subtracting the flight time to the target for each vehicle from those respective times at the target.

The planned event matrix called for a beacon and a probe rocket to be launched in conjunction with the developed Event GAIL ion cloud. Two beacon vehicles were planned with the Event HOPE cloud. A beacon-probe combination was to support the Event IRIS release. The Event JAN release would allow for companion vehicles that had not been fired during the previous operations to be flown or would provide an additional release for the airborne communications experiment only.

The experiments that called for a beacon and probe launch required the occultation and penetration to occur simultaneously. This condition was implemented by targeting the beacon vehicle first, since it had the longer flight time, and then targeting the probe vehicle on the same target time while allowing cloud-tracking data to accumulate. It was determined prior to the test series that the probe vehicle targeting-computation sequence could be completed two or three times after the completion of the launch-preparation sequence for the beacon vehicle and still accomplish a simultaneous beacon occultation and probe penetration. This could be done primarily because of the difference in the probe and beacon flight times to the target.

Range Safety

The fixed or permanent points and areas that had to lie outside of the possible vehicle impact zones included oil platforms off the Mississippi Delta and south of Mobile Bay, an oil exploration area in the gulf southwest of Panama City, Florida, and the entire western coast of Florida. The 3σ dispersion area for all of the PLACES payloads and second-stage boosters was conservatively determined to be circular with a 3σ radius of 57 km for the complete extent of expected elevation launch angles.

A nominal impact limit line was established using the criteria of a 3σ radial-distance separation from all oil drilling and exploration points and a 6σ radial-distance separation from the western Florida coastal areas. This nominal impact limit line is shown on Fig. 3. The 3σ impact areas for the PLACES payloads and second-stage boosters, also presented in Fig. 3, reflect the total expected barium ion cloud-drift area mentioned previously plus drift distances up to 40 km. The payload 3σ impact areas for the beacon and probe vehicles reflect the passing of the beacon payload 100 km behind the ion cloud for occultation and the passing of the probe vehicle through the ion cloud for penetration for all cloud positions within this pie-shaped sector. The ion cloud altitude was assumed to be 175 km which allowed for cloud descent during cloud development. The 3σ payload and second-stage booster-impact area labeled "Ba Carrier" on Fig. 3 is centered on the nominal impact point of the Event GAIL barium vehicle.

Trajectory Simulation (On Site)

Exoatmospheric point-mass trajectory simulations for the barium carrier, beacon, and probe vehicles were computed on the main field minicomputer. A rotating, oblate-spheroid Earth model (International) was applied. The trajectory code integrated the equations of motion to determine the vehicle's position and velocity in the master coordinate system. The initial conditions for the exoatmospheric trajectory simulation included position in the master coordinate system (X_0, Y_0, Z_0), corresponding velocities in the coordinate directions (V_{x0}, V_{y0}, V_{z0}), and the t_0 (vehicle flight time from booster ignition to atmosphere exit). The edge of the atmosphere was considered to be at 300 kft (91.4 km) altitude.

An array of these initial conditions was determined for each vehicle type prior to the field work by using a six-degree-of-freedom trajectory simulation code.[4] Complete trajectory simulations were computed for each vehicle type at discrete values of launch azimuth and elevation. Then the two-dimensional array of the initial conditions was produced for each vehicle type, with launch azimuth and elevation as the independent variables extending over the complete range of allowed launch angles from range-safety considerations.

This method of computation provided a real-time field capability of trajectory computation on a minicomputer. The program had to be small and not require large storage because the computer was also being used to compute predicted barium-cloud position and wind-effects launcher-angle corrections with the associated memory requirements. The computational approach provided sufficient accuracy; the maximum position error at re-entry (300 kft, 91.4 km; vehicle descent) noted in comparison with complete six-degree-of-freedom trajectory computations was 150 m. The integration time interval applied in the on-site trajectory-simulation code was 0.5 s.

The field computation of the actual trajectory for all vehicles avoided the need for large three-dimensional space-position tables with launch angles as dependent variables that, in turn, reduced the number of six-degree-of-freedom trajectory simulations required prior to the field work.

A real-time computation of the companion vehicle second-stage booster and payload-impact point was also provided by the point-mass trajectory simulation code. Once the nominal trajectory for the vehicle flight to the target was determined, a complete trajectory to impact on the tangent plane without atmosphere was computed and assumed to simulate the flight of the actual vehicle (comparison with six-degree-of-freedom computations indicated typical inaccuracies of the impact point prediction to be less than 1.5 km). The field com-

Table 1 Impact point error summary

	Actual impact			Predicted impact			X,	Y,	Deviation,
Event/vehicle	t, s	X, km	Y, km	t, s	X, km	km	km	km	σ
GAIL									
Ba Carrier	433.3	338.5	−174.4	437.3	337.2	−170.7	1.3	−6.9	0.2
HOPE									
Ba Carrier	437.0	354.7	−69.4	436.5	375.6	−62.5	−20.9	−3.7	1.2
IRIS									
Ba Carrier	419.0	411.3	−87.3	420.1	402.5	−87.0	8.8	−0.3	0.5
IRIS									
Beacon No. 1	508.8	301.2	−28.1	521.4	304.4	−21.1	−3.2	−7.0	0.4
IRIS									
Beacon No. 2	503.2	342.3	−21.8	511.3	354.3	−5.6	−12.0	−16.2	1.1
JAN									
Ba Carrier	434.2	372.0	−51.4	436.7	381.2	−36.3	−9.2	−15.1	0.9
JAN									
Probe	477.0	424.2	−50.9	497.5	462.0	−20.4	−37.8	−30.5	2.6

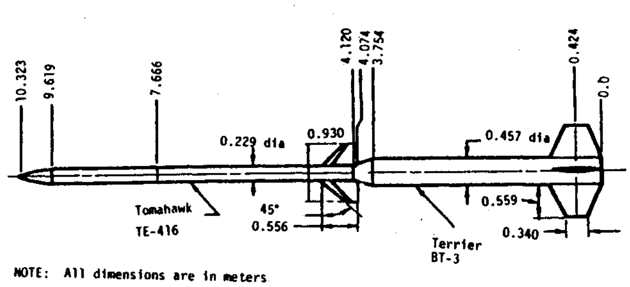

Fig. 4 Terrier-Tomahawk 9 rocket system (PLACES beacon payload).

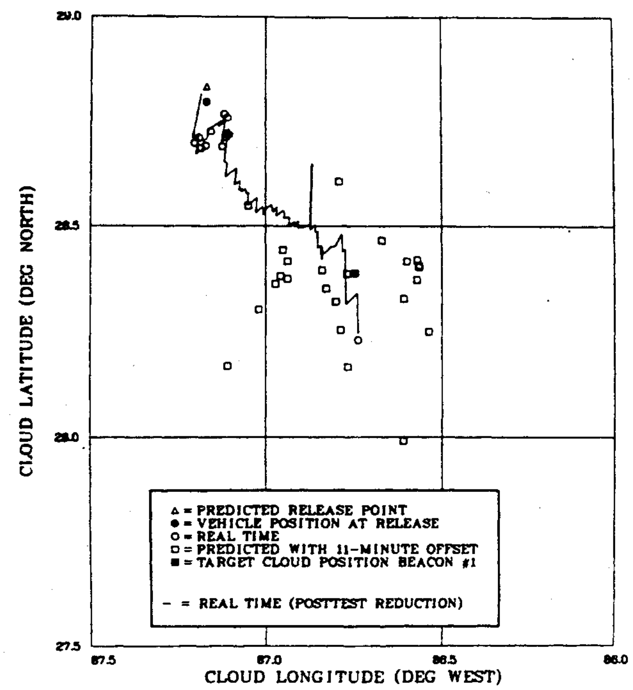

Fig. 5 Cloud latitude vs cloud longitude for Event IRIS (beacon axis-probe plane).

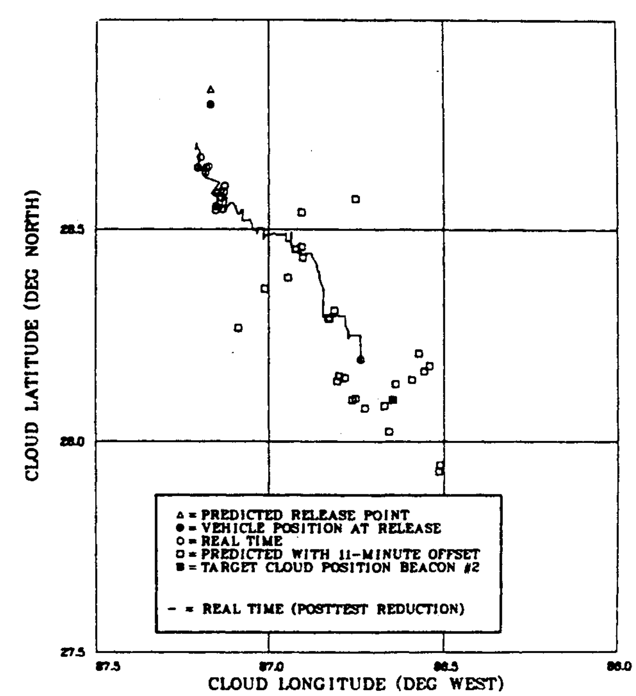

Fig. 6 Cloud latitude vs cloud longitude for Event IRIS (probe axis-empirical height).

putation of the predicted impact point was used for range-safety evaluation during the field operation.

Vehicle Nominal Trajectory Determination

The nominal vehicle trajectory and, thus, the nominal launch angles for each rocket system (launcher elevation and azimuth) were determined by using a simple iterative computation procedure implemented on the main field minicomputer. The vehicle target (the preselected nominal release point for a barium carrier, the offset-time predicted 100-km occultation point for a beacon vehicle, or the offset-time predicted cloud position for a probe vehicle), the vehicle table of exoatmospheric flight initial conditions, and the exoatmospheric point-mass trajectory code were combined in the computation process that is described below.

1) The target point (X, Y, Z position in the master coordinate system) was determined as discussed previously.

2) The initial-condition table for the type of vehicle being targeted was called from computer memory.

3) The azimuth of the target point from the launcher was computed and was applied as "first-guess" of the vehicle launch azimuth.

4) The "first-guess" of the vehicle launch-elevation angle was preset at 78 deg (the first and second guesses of the elevation launch angle were preselected as being an approximate average of the expected final elevation-launch angles of all vehicles).

5) An initial trajectory simulation was computed and terminated at the target-Z elevation (termination on the trajectory upleg for a barium carrier or a probe vehicle and on the trajectory downleg for a beacon vehicle).

6) The "second-guess" launch azimuth was determined by modifying the "first-guess" by the difference between the target azimuth and the azimuth of the trajectory simulation termination point.

7) The "second-guess" of the vehicle launch-elevation angle was preset at 80 deg.

8) A second trajectory simulation was computed.

9) A "third-guess" launch azimuth was determined by modifying the "second-guess" by the difference between the target azimuth and the azimuth of the second trajectory simulation termination point.

10) The sensitivity of range ($\sqrt{X^2+Y^2}$) in the tangent plane at the target-Z position to the launch-elevation angle was determined using the first two trajectory simulations. This sensitivity, the target tangent-plane range, and the range at the target-Z position for the "80-deg" simulation were then combined to determine a "third-guess" of the launch-elevation angle.

11) The procedure was continued for launch-azimuth angle as described above and for launch-elevation angle with a Newton-Raphson computation technique to match the target tangent-plane range with that of the simulation at the target-Z position. The iterations were continued until the position error in X and Y combined was less than a preset criteria (0.5 km was used during all actual targeting computations). This accuracy was usually obtained in five iterations. The vehicle nominal launch angles were those angles input for the trajectory simulation of the final iteration.

Launch Angle Wind Corrections

Since the interception of the predicted target points by any of the vehicles required that they all fly as closely as possible to the predicted trajectory and since the atmospheric wind profile has a relatively large effect on the vehicle launch angles (2 deg elevation and 10-20 deg azimuth corrections are not uncommon), a wind profile update procedure that could be implemented continuously was necessary. The wind speed and direction data from three elevation stations on a launch-site wind tower were used to update the wind profile every 3 s and a continuous series of wind balloons was released and tracked to allow continuous updating of the wind zones above the tower height. During the time of vehicle targeting and launch sequences, a continuous series of balloons was released and tracked to 5000-ft altitude to obtain a near-continuous updating through the altitude zones in which the vehicles are the most wind sensitive. Profiles of the upper winds were obtained with high-altitude balloons released earlier. The wind profile updating computational procedure is described in Ref. 5.

Terrier-Tomahawk 9 Rocket System

The TT9 rocket system is a two-stage, solid propellant, unguided vehicle that has been used to boost 9-in.-diam (22.9 cm) payloads of mass variation from 75 to 150 kg and of length variation from 2.108 to 3.302 m. The system is capable of boosting payloads with the above mass extremes to 400 and 245 km, respectively. A sketch of the TT9 vehicle with a PLACES beacon payload attached is shown in Fig. 4.

The first- and second-stage motors are connected with a slip-fit, conical interstage adapter that is clamped to the Terrier motor and slides into the Tomahawk nozzle exit cone and throat. The first-stage booster separates from the second-stage system as the Terrier motor burns out because of the aerodynamic drag/mass differential. The first-stage vehicle is aerodynamically stabilized with four trapezoidal-planform, double-wedge section Terrier tail fins that have a plan area of 0.321 m^2 each. The second-stage vehicle is aerodynamically stabilized with four swept-leading-edge, flat-section Tomahawk tail fins (mounted in-line with the Terrier fins in cruciform configuration) that have a plan area of 0.134 m^2 each.

The performance of the TT9 rocket system may be described by a brief discussion of a typical PLACES rocket-system trajectory. The flight sequence of a PLACES beacon vehicle (106-kg payload) launched at a quadrant elevation angle of 80 deg is described below. The Terrier motor is ignited at zero time (t-zero). The first-stage vehicle is rail-guided on the launcher for a distance of 5.24 m and then released (launched). The vehicle speed is approximately 43 m/s and the altitude of the system center of gravity is 13 m mean sea level (msl) at launch which occurs at $t+0.30$ s. The Terrier motor burns out and separates from the Tomahawk at $t+5$ s at a speed of 1006 m/s and an altitude of 2195 m. The second-stage vehicle coasts for approximately 13 s before the Tomahawk motor is ignited. Some flight conditions at Tomahawk ignition are $t+17.6$ s, speed 671 m/s, altitude 12.8 km, and elevation flight-path angle 76.9 deg. The Tomahawk motor burns for approximately 9 s. Some flight conditions at Tomahawk burnout are $t+26.5$ s, speed 2408 m/s, altitude 25.9 km, elevation flight-path angle 76.0 deg, and Mach number 7.9. The second-stage vehicle leaves the atmosphere (altitude 300 kft msl, 91.4 km) at $t+57.5$ s with an elevation flight-path angle of 74.0 deg. The vehicle continues to an apogee of 303 km at 141 km downrange distance and $t+274$ s. Vehicle impact occurs at $t+535$ s at a downrange distance of 284 km.

PLACES Test Results

There were no companion vehicles (beacon or probe) launched with the developed GAIL (12-04-80) or HOPE (12-06-80) barium ion clouds. During striation development, neither cloud track direction was within the limits of the azimuthal sector from the release point. Thus, additional launches were prevented because of range safety constraints.

Two beacon vehicles were scheduled with the IRIS release because of the higher program priority of the beacon experiment. No additional launchers were available for a probe vehicle. After the IRIS release (12-08-82), data from both TV trackers were processed and applied for predicting future cloud positions to allow targeting of the beacon vehicles. The predicted cloud positions exhibited some scatter because of the discrete nature of the TV trackers. A predicted cloud position, which appeared to be "in-line" with the real-time cloud track, was chosen for final targeting of both beacon vehicles at their respective launch preparation times. The beacon-axis, probe-plane TV-tracker solution was used for targeting the first beacon vehicle (targeted for the predicted position of the striated ion cloud at R+32-½ min). The probe-axis empirical-height, TV-tracker solution was used to target the second beacon vehicle (targeted for the predicted position of the striated ion cloud at R+45-¼ min). A longitude-latitude plot of the predicted cloud locations, real-time cloud track, and the predicted cloud points used for final targeting each beacon vehicle are presented on Figs. 5 (beacon No. 1) and 6 (beacon No. 2). Experimental data indicated that both beacon vehicles were occulted by the striated ion cloud as viewed from both beacon receiver sites.

The cloud track direction after the JAN barium release (12-12-80) was also outside the expected azimuthal sector. Range safety constraints prevented the launch of a beacon vehicle. However, a probe vehicle was launched, penetrated the striated portion of the ion cloud, and obtained in-situ measurements of the disturbed environment. Reference 6 describes the PLACES test results in greater detail than can be presented here.

Rocket Vehicle Actual Trajectories

Excellent radar-tracking data were obtained during all flight tests. A C-band radar transponder was included in all vehicle payloads, and two or three independent radar tracks were obtained on each vehicle. The radar-tracking data were used to compare the actual vehicle trajectory with that predicted prior to flight. A summary of the payload-impact errors is presented in Table 1.

The average payload-impact error, excluding the Event JAN probe vehicle, was 0.7σ. The probe vehicle was launched with an approximate launch-angle correction to compensate for atmospheric winds. The computer that determines the amount of wind compensation required and the corresponding elevation and azimuth angle changes was not operating during the probe vehicle-launch targeting. The angle corrections made were based on those used for the Event

Table 2 Payload targeting error summary

					Target points tangent plane coordinates								
					Actual position			Nominal position			Error		
Test date	1st motion time (GMT)	t 1st motion to event, s	Release/ vehicle	Time of event (GMT)	X, km	Y, km	Z, km	X, km	Y, km	Z, km	X, km	Y, km	Z, km
12-04-80	2304:59.87	155.94	GAIL/Ba	2307:35.8	119.92	−59.65	177.39	115.93	−56.61	183.73	3.99	−3.04	−6.34
12-06-80	2305:00.25	157.60	HOPE/Ba	2307:37.9	126.45	−22.80	179.62	129.74	−19.67	183.68	−3.29	−3.13	−4.06
12-08-80	2309:59.91	187.40	IRIS/Ba	2313:07.3	181.65	−36.55	177.01	177.35	−36.51	187.49	4.30	−0.04	−10.48
12-08-80	2338:36.9	402.4	IRIS/Be 1	2345:19.3	242.85	−23.03	174.64	249.11	−17.56	185.18	−6.26	−5.47	−10.54
12-08-80	2351:36.26	403.5	IRIS/Be 2	2358:19.8	279.31	−17.69	−166.05	285.58	−4.78	186.59	−6.57	−12.91	−20.54
12-12-80	2311:00.03	161.57	JAN/Ba	2313:41.6	136.41	−17.01	181.01	139.36	−11.35	188.50	−2.95	−5.66	−7.49
12-12-80	2342:50*	110.00	JAN/Pr	2344:40	91.29	−7.61	157.27	98.95	−0.58	167.73	−7.66	−7.03	−10.46

*approximate

JAN barium-carrier vehicle (launched 30 min earlier). A near-nominal impact could not be expected with such a launch-angle correction procedure. However, an impact within the range-safety 3σ limit was achieved.

A summary of the payload-targeting errors is presented in Table 2. The nominal and actual target coordinates are presented for comparison. The nominal positions for the barium-carrier vehicles are the respective nominal release points, which are different for each release. The nominal positions for the beacon vehicles and the probe vehicle are the occultation points and the penetration points, respectively, that correspond to the predicted ion cloud positions. The actual positions for the barium vehicles correspond to the vehicle radar track at the times that the barium releases were initiated. The actual position for a beacon vehicle corresponds to the vehicle radar track at the average time of the midpoints of the two time intervals of occultation at the receiver sites. The actual position for the probe vehicle corresponds to the vehicle radar track at the time of peak electron density measured during ion cloud penetration.

Conclusion

The PLACES ionospheric plasma test series was considered to be successful. Experimental data which met test objectives were obtained on the three instrumentation vehicles (two beacons and one probe) launched during the series. The real-time cloud tracking and instrumentation vehicle targeting procedures worked well during the operation. The Terrier-Tomahawk booster systems and payload sequencing and attitude control system (probe payload) performed as expected.

Acknowledgments

This work was performed at Sandia National Laboratories supported by the U.S. Department of Energy under Contract DE-AC04-76DP00789 for Defense Nuclear Agency.

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