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Automatic Detection of Low Altitude Wind Shear Due to Gust Fronts in the Terminal Doppler Weather Radar Operational Demonstration*

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ABSTRACT

A gust front is the leading edge of the cold air outflow from a thunderstorm. Wind shears and turbulence along the gust front may produce potentially hazardous conditions for an aircraft on takeoff or landing such that runway operations are significantly impacted. The Federal Aviation Administration (FAA) has therefore determined that the detection of gust fronts in the terminal environment be an integral part of the Terminal Doppler Weather Radar (TDWR) system. Detection of these shears by the Gust Front Algorithm permits the generation of warnings that can be issued to pilots on approach and departure. In addition to the detection capability, the algorithm provides an estimate of the wind speed and direction following the gust front (termed wind shift) and the forecasted location of the gust front up to 20 minutes before it impacts terminal operations. This has shown utility as a runway management tool, alerting runway supervisors to approaching wind shifts and the possible need to change runway configurations.

The formation and characteristics of gust fronts and their signatures in Doppler radar data will be discussed. A brief description of the algorithm and its products for use by Air Traffic Control (ATC), along with an assessment of the algorithm's performance during the 1988 Operational Test and Evaluation, will be presented.

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AUTOMATIC DETECTION OF LOW ALTITUDE WIND SHEAR DUE TO GUST FRONTS IN THE TERMINAL DOPPLER WEATHER RADAR OPERATIONAL DEMONSTRATION

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109217-4

OVERVIEW

- FORMATION AND CHARACTER OF GUST FRONTS
- GUST FRONTS AS AN AVIATION HAZARD
- GUST FRONT SIGNATURES IN DOPPLER RADAR DATA
- GUST FRONT ALGORITHM AND PRODUCTS FOR ATC
- GROUND TRUTH AND SCORING
- RESULTS FROM 1988 TDWR OT&E
- ONGOING WORK
- CONCLUSIONS

109217-5

FORMATION AND CHARACTERISTICS

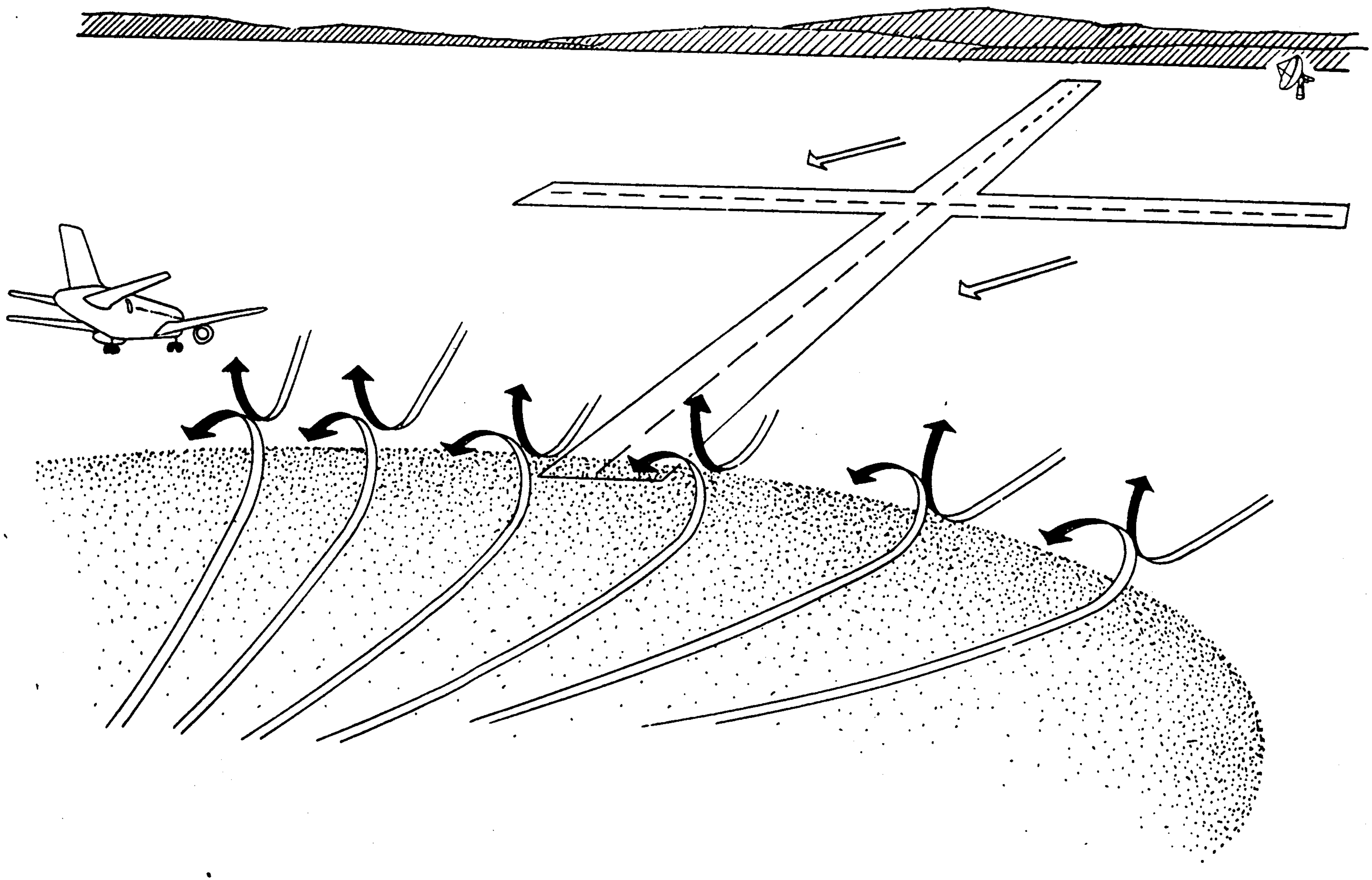
A gust front is the leading edge of the cold air outflow generated when the downdraft from a thunderstorm reaches the ground and spreads horizontally. The outflow can propagate many kilometers from the parent storm and may continue to exist after the parent storm has dissipated. The passage of a gust front is identified by a sharp drop in temperature and strong gusty winds (from which the name "gust front" is derived).

AVIATION HAZARDS

Because gust fronts can move far from the parent storm, there may be no visual clues to a pilot that a gust front is in the vicinity. An aircraft that encounters a gust front during takeoff or landing typically experiences a gain in the headwind. This may cause a landing aircraft to land long. Hazardous turbulence and downdrafts have also been reported in association with gust fronts

The wind shifts that accompany gust fronts can disrupt airport operations by necessitating the reconfiguration of runways, resulting in costly delays. Advanced warning of a gust front can be used for planning purposes.

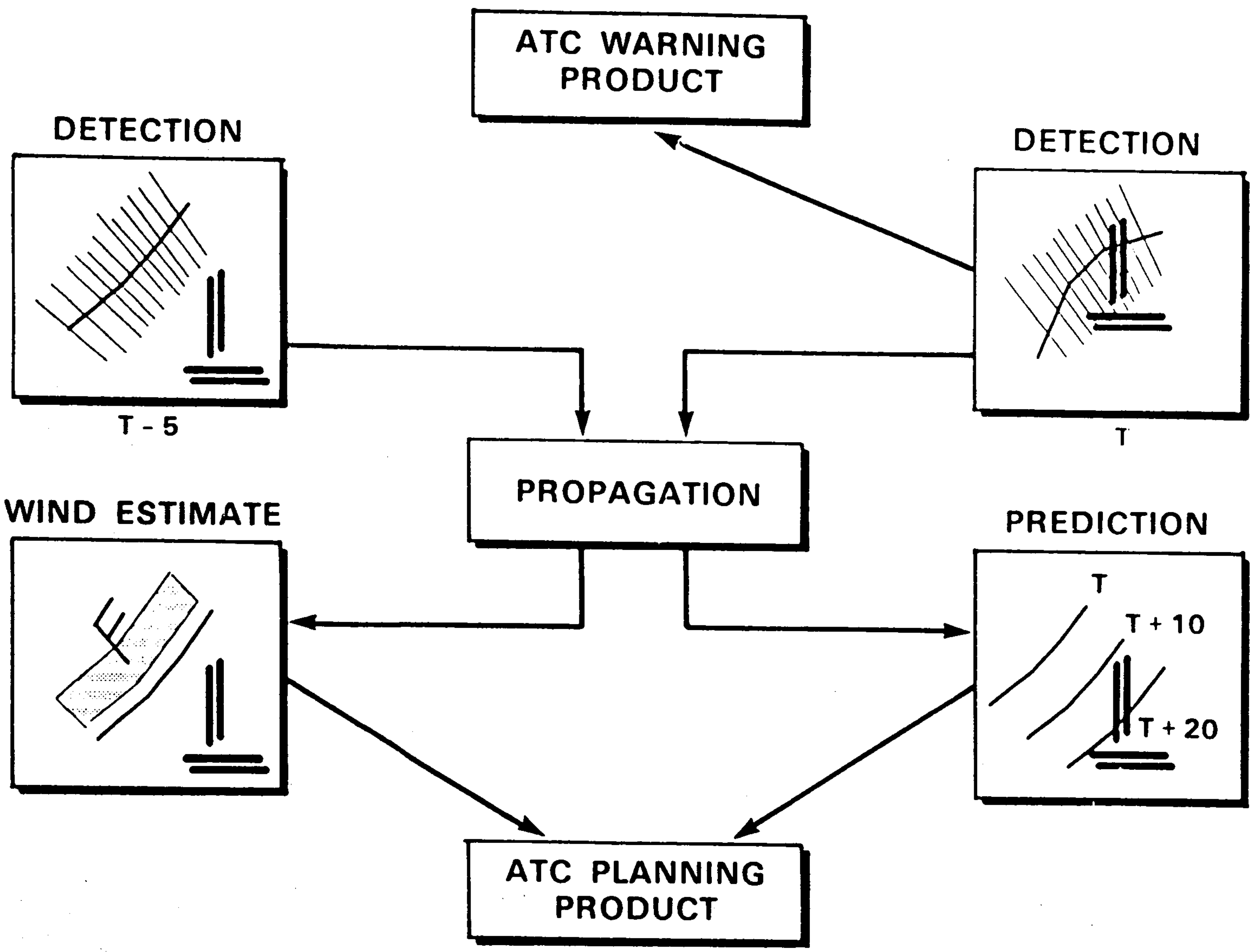
GUST FRONT/WIND SHIFT



GUST FRONT ALGORITHM AND ATC PRODUCTS

In simplified terms, the Gust Front Algorithm searches along radials for segments of converging radial velocities. These segments are associated, based upon spatial proximity, into gust fronts. If a gust front impacts the runways (time T), the mean and standard deviation of the peak shears along all associated segments are computed and summed to determine the wind shear value encoded into the warnings issued by the Air Traffic Controllers to pilots.

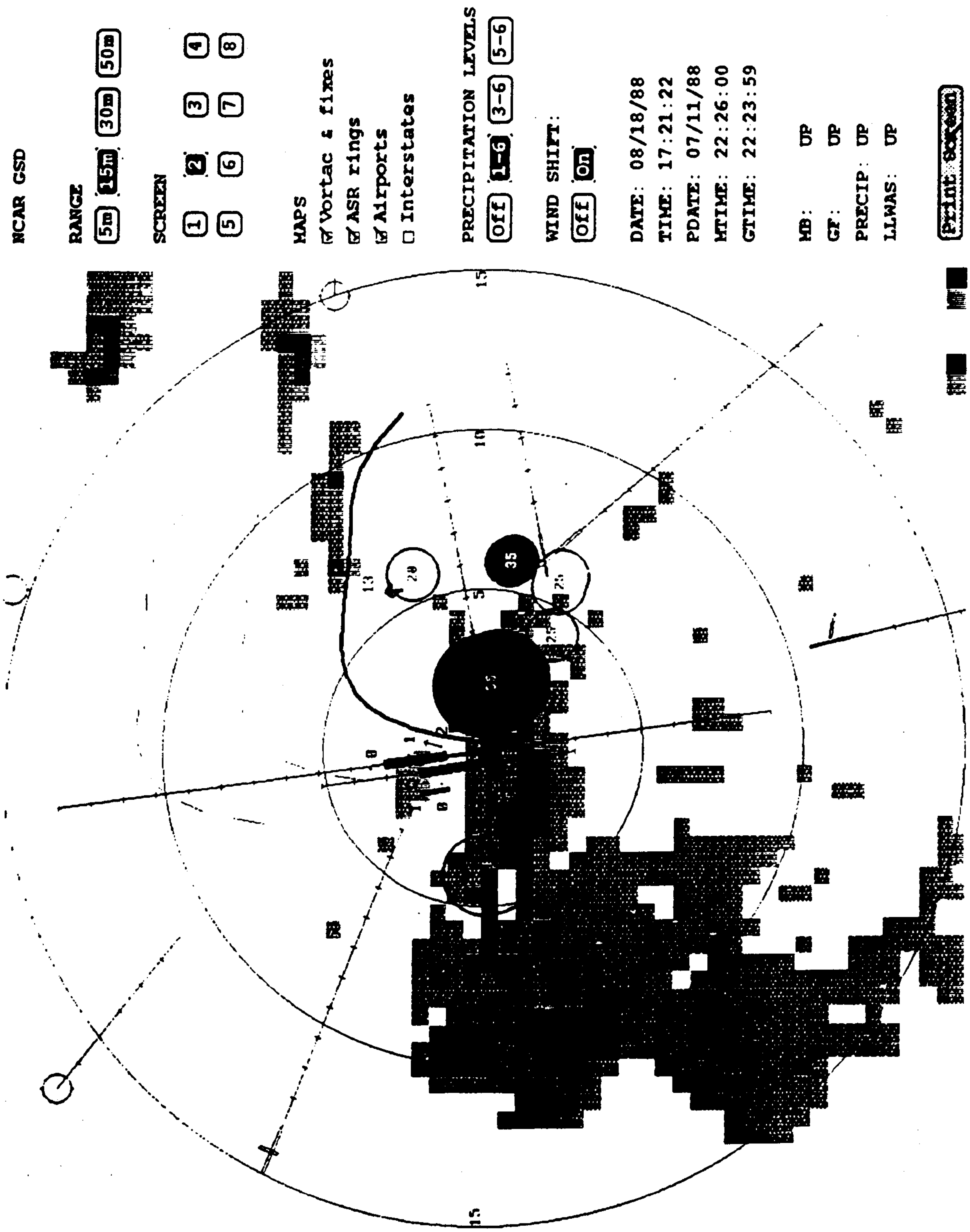
Once a gust front is detected on two consecutive scans (at time T−5 and T), its propagation speed and direction are computed. From this it is possible to forecast the location of the gust front at 10 and 20 minutes. An estimate of the wind speed and direction behind the gust front is computed. This information is passed to the Air Traffic Control Supervisor who determines if runway reconfiguration is necessary.


ATC WARNING PRODUCT
DETECTION
T - 5
DETECTION
T
PROPAGATION
WIND ESTIMATE
PREDICTION
T
T + 10
T + 20
ATC PLANNING PRODUCT

109217-10

GEOGRAPHIC SITUATION DISPLAY (GSD)

This is an example of the display of the algorithm products presented to Air Traffic Control Supervisors at Stapleton International Airport on 11 July 1988. The detected position of the gust front is given by a solid purple line and 10 and 20 minute forecasts positions by dashed lines. The estimated direction of the wind behing the gust front is indicated by an arrow and wind speed by a numerical value. The red circles are microbursts. The proximity of the gust front to the runways causes a wind shear alert message to be issued to Air Traffic Controllers, which is then passed to pilots. Here, microburst alerts override gust front alerts on the east–west runways, but gust front alerts are issued for the north–south runways.



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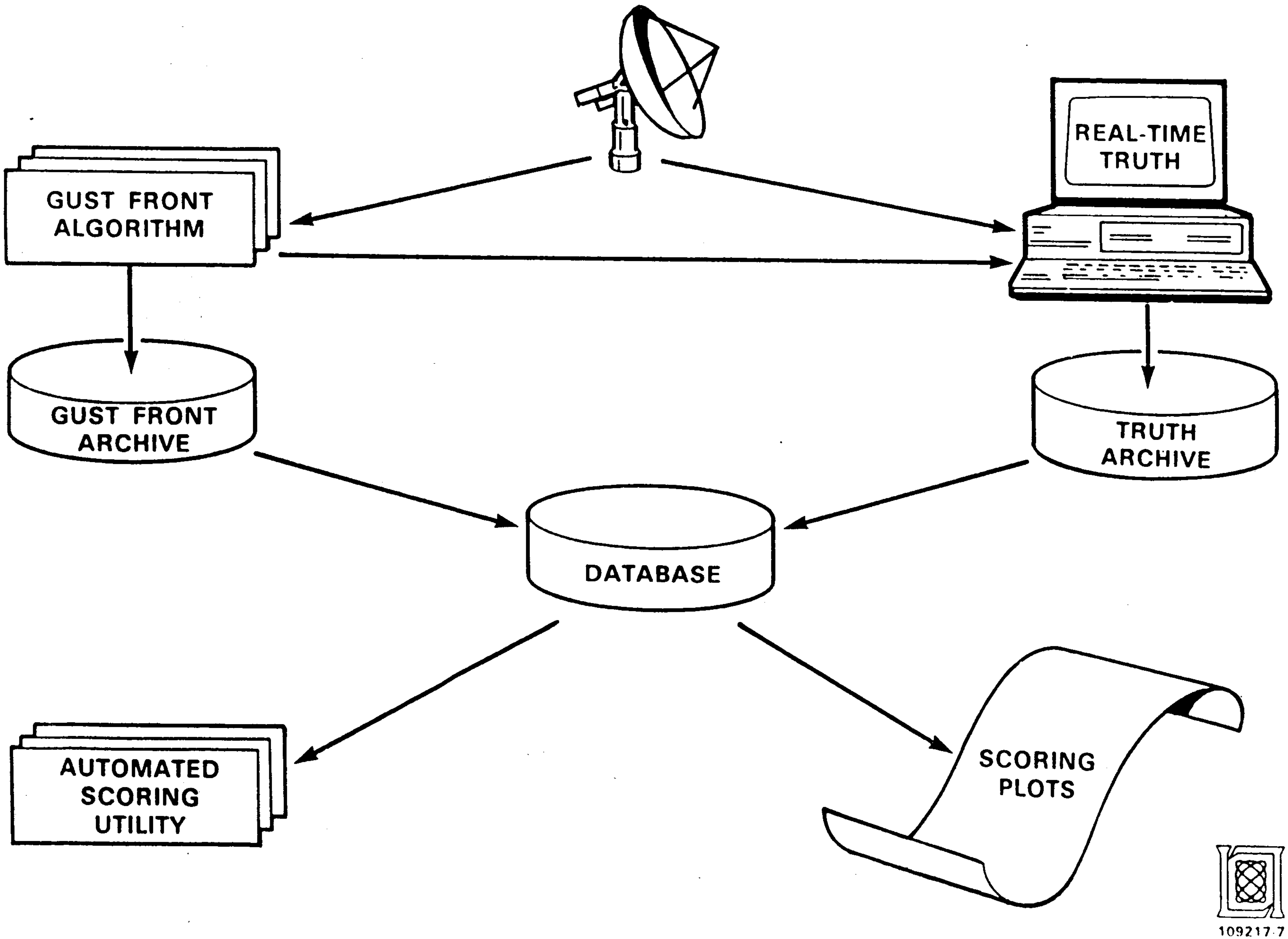
SUPPORT SOFTWARE

The performance assessment of the Gust Front Algorithm is assisted by software that allow the generation and archival of ground truth and algorithm outputs in real-time and automated scoring offline.

In real-time, radar data are passed to the Gust Front Algorithm for processing. Algorithm outputs are written tc an archive file and, along with the raw data, are displayed on a Sun workstation. A weather expert enters into a ground truth data file the strength and location of all gust fronts. This file is converted offline into an archive file.

The ground truth and algorithm archive files are merged into a database. These data are then passed through software that automatically computes the probability of detection and probability of false alarm.

GUST FRONT SUPPORT SOFTWARE



RESULTS

Results of the performance assessment of the Gust Front Algorithm are shown here. POD is Probability of Detection, PFA is Probability of False Alarm. For hazard warnings, these statistics refer to gust fronts that occurred in the vicinity of the airport. For the planning function, POD and PFA refer to all gust front within 60 km of the radar.

PCF is the Probability of Correct Forecast and PFF is the Probability of False Forecast. A correct forecast is one that falls within the truth box at the time for which the forecast is valid. If the gust front dissipates before the forecast is valid, a false forecast is declared. Although the PCF for the forecasts is high, forecasts were issued for only 45% of the 270 gust fronts that occurred during the analysis period.

Ground truth for the wind shift estimate is derived from mesonet data. Thus only wind shifts for those gust fronts that passed through the mesonet (*i.e.*, over the airport) are scored.

Air Traffic Control Supervisors were asked to assess the usefulness of the planning function for the Gust Front Algorithm. Their responses are shown here.

RESULTS

HAZARD WARNINGS

- POD = 0.70 PFA = 0.02
- WIND SHEAR INTENSITY ERROR = 10 KNOTS

PLANNING FUNCTION

- DETECTION
  - POD = 0.76 PFA = 0.02
- FORECASTING (When Possible)
  - PCF = 0.95 PFF = 0.11 (10 min)
  - PCF = 0.83 PFF = 0.18 (20 min)
- WIND SHIFT ESTIMATE
  - SPEED ERROR = 3 m/s
  - DIRECTION ERROR = 30°
- CONTROLLER ASSESSMENT (7 Supervisors)
  - 3 VERY GOOD, 2 GOOD, 1 FAIRLY GOOD, 1 FAIR

109217-1

ONGOING WORK

Although the Gust Front Algorithm detected over 75% of the gust fronts, only about 70% of their total length was found (which corresponds to about 85% of the convergent portion of gust fronts). There exists a need to improve the convergence detection. This will result in better warnings and forecasts. One way to accomplish this is to relax the shear thresholds once a detection has been declared to help fill in missing portions.

Tracking of gust front is accomplished by centroid tracking. The position of the centroid is dependent upon the detected length of the gust front. If the percent of the detected length varies greatly from scan to scan, the centroid does not well represent the gust front motion and the gust front can appear to propagate in the wrong direction. A better gust front tracker is needed.

The intensities for the pilot warnings tended to be too large. In addition, pilots often report turbulence in the vicinity of a gust front. Thus, the pilot warnings need to be revised to more closely reflect the hazards that the pilots encounter.

The ability to detect the thin line and azimuthal shears associated with gust fronts will improve detection.

ONGOING WORK

- IMPROVE CONVERGENCE DETECTION
- ADD THIN LINE AND AZIMUTHAL SHEAR DETECTION
- IMPROVE TRACKING/FORECASTING
- IMPROVE PILOT WARNINGS

109217-2

CONCLUSIONS

- AUTOMATIC DETECTION OF GUST FRONTS ESSENTIAL FOR TERMINAL SURVEILLANCE

- GUST FRONT ALGORITHM PROVED OPERATIONALLY USEFUL IN HAZARD DETECTION AND PLANNING FUNCTION

- REFINEMENTS AND ENHANCEMENTS UNDERWAY

109217-3