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BROADCAST CONTROL OF AIR TRAFFIC

3rd Quarterly Progress Report

NASW 2247

George Litchford
LITCHFORD SYSTEMS

March 1972

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WIDE RANGE OF BROADCAST CONTROL CONCEPTS

With the introduction of LF/VLF systems, such as Omega and Loran-C, new geometric navigational coordinates will exist that offer many options to the planners of systems for "Broadcast" control of air traffic. In the simplest case, the several lines of position (LOP's of station combinations) create overlapping parallel-oblique lines that often approximate a rectilinear coordinate system. With simple coordinate conversion of these simple LOP's, new coordinates can be created for airways or to form a flight track between any two points.

This VLF airway is then displayed to the pilot with nearly any direction and sensitivity desired since VLF coordinates are universal and contiguous across the nation. Several developments are underway for a "pure" VLF type system that can be utilized by general aviation. We can utilize new airspace for airways not now available, yet suited to the unique requirements of general aviation. Less conflict between general aviation and the airlines and airports and airways is expected as one important product of this plan.

It is possible to postulate a dual system of airways that would essentially (1) utilize VORTAC for providing R-NAV airways to the airliner and jet aircraft operations, and (2) parallel (VLF-Omega) R-NAV airways to the side and at lower altitudes for general aviation's slow, light aircraft.

The problem has always been the electronic definition of airspace suitable for air traffic control. The national constraints of using only the VORTAC system for R-NAV is that only a fraction of the airspace suitable for airways and ATC can be used because

of the current "radial-only" concepts of using VORTAC. To state this in different words: a great deal of useful airspace exists that cannot be used today since the method of defining or assigning airspace by ATC authority to aircraft is too antiquated. No estimate has been made on a national basis, but it is likely that, if all the airspace that would be of value to air traffic of 1980-1990 were identified, perhaps less than half of it can be adequately authorized for use in ATC concepts since the limitations of radial-only exist. Locations of the VORTAC stations, convergence of tracks, or line-of-sight propagation limitations, prevents expanded VOR use.

We could probably double the nation's airspace useful to ATC and for airways and airport approaches with adequate coordinates by adopting a new VLF electronic Navigation system. Broadcast control concepts of air traffic control would then be easily instituted with major savings.

Shortly the national cost to move in this direction will become insignificant when compared to the large benefits. Much of the demand for some form of traffic control suitable for this large, unused volume of airspace must be satisfied. The user's cost for deriving benefits from this newly created airspace must be very low to accommodate general aviation's nearly 100,000 small aircraft.

A recent national conference on R-NAV indicates VORTAC Area-Nav costs cannot be reduced adequately to attract the lower 85 percent economic strata of general aviation (references 1, 2 and 3).

In addition to a supplemental ATC system for general aviation and Broadcast control, which is only an LF/VLF system, it is also possible to postulate a means of interfacing and combining the current VOR system with the current VLF system (Omega is fully operational in 1974).

VOR AND VLF NAVIGATION INTEGRATED FOR ATC AND AIRWAYS

We will assume the nearly 1,000 VOR stations that now exist will remain. The most prevalent avionics unit in an aircraft today, aside from VHF-COM, is the VOR NAV receiver, so we can build our concepts on a large installed fleet of VOR receivers in general aviation aircraft. These VHF receivers have been brought down in price so that cost is no longer a constraint in VOR usage. This, however, is not true when DME is added along with a costly R-NAV computer and its display.

This is to say the cost of a VOR receiver is in the 500 to 1,000 dollar range, while the added elements to achieve Area-Nav (DME, computer, displays) are still in the total price range of from 6,000 to 15,000 dollars, depending upon the extent of computing desired. If altitude correction and three-dimensional navigation are essential, as it now appears (references 1, 2 and 3), the cost then can range above 15,000 dollars for the lowest cost "package" for R-NAV with VORTAC. Defining airways based on many randomly located spherical coordinates is costly and can only be justified by high performance of jet aircraft, thus denying this service to others, since airspace once assigned to R-NAV airways can only be used by those aircraft so equipped.

The concepts presented here are intended to overcome this national dilemma which is now clearly in focus from a review of the recent national conference on R-NAV (January 1972). Basically, the idea is to (1) utilize the VOR with its known strengths and weaknesses; and (2) a system like Omega with its known strengths and weaknesses; in a (3) newly combined and harmonious relationship. In this combination the strengths of one system overcome the weaknesses of the other system.

Table I summarizes some of the methods of overcoming the weaknesses of one system with the strengths of the other system. For example, the very existence of about 1,000 VOR stations, each with a voice channel to the pilot, makes it possible to locally add simple "differential" VLF correction data that can manually or automatically correct the VLF receiver. This directly solves one of the most vexing VLF problems: the "diurnal correction." Another example suggested by Table I is the use of the naturally parallel LOP's of Omega to overcome the converging LOP's of VOR causing airway convergence to a central point which inhibits traffic flow and overloads ATC. Opening up the total national airspace with non-converging airways avoids these constraints and makes ATC much simpler, providing airways in about twice the amount of airspace than is now possible.

PROVIDING ENORMOUS NEW AIRWAY CAPACITIES FOR GENERAL AVIATION AND V/STOL

It can be seen in Table I that these many complementary aspects come from a "mix" of VHF techniques and VLF techniques, from two systems that already exist. Each covers the entire

TABLE I

COMBINATION OF VOR-OMEGA OFFSET WEAKNESSES AND OPTIMIZE STRENGTHS OF BOTH SYSTEMS

VOR	ADVANTAGES OF COMBINATION	OMEGA
VOR STRONG POINTS		**VLF(OMEGA) WEAK POINTS**
1. 1,000 ground stations 2. Most aircraft equipped	Combination voids need for DME in air or more VOR stations	1. Almost no airborne units at present (all ground stations operational by 1974)
3. Voice channel to air to convey automated voice data (diurnal, baro, etc.)	Voice automated diurnal from all VOR stations	2. Needs diurnal corrections
4. No ambiguities over 360°	VOR solves ambiguities and provides waypoints	3. Resolution of ambiguities
5. Familiar to all pilots	Use same type airway deviation display	4. New to pilots
6. Real estate, power, monitors, telephone lines all in operation	Locate OMEGA monitors at VOR sites	5. Needs diurnal correction and monitor receiver each (area) 100 X 100 miles
VOR WEAK POINTS		**VLF(OMEGA) STRONG POINTS**
1. Line-of-sight only	VLF prevent loss of airway guidance beyond line-of-sight of VOR	1. Beyond line-of-sight, and on surface
2. National coordinates are very complicated		2. Simplified national coordinates
3. Required DME for R-NAV	DME equivalency	3. Crossing LOP's give distance data along airway-LOP
4. Requires altitude correction for many R-NAV services (refs.1,2,3) 5. Requires "3-D" airway computer	Lowers costs in airway computer	4. No altitude corrections needed 5. Simplified "oblique-parallel" geometric computer of airways
6. Total R-NAV costs about 5 - 10 times VOR costs	Lowest economic level general aviation can afford; benefits many times costs	6. Production should cost about twice a VOR receiver
7. Random spherical coordinates 8. Accuracy varies with range, azimuth and individual station	Constant accuracy VOR supplies waypoints	7. Contiguous coverage R-NAV by reception only little channel space required

Preliminary Draft

Unites States--VLF more completely and usefully than VOR. Some would use VLF for tracks or airways and VOR for "waypoints" or longitudinal control of ATC. As far as spatial coordinates are concerned, VOR is a spherical coordinate system (when combined with DME). VLF-Omega retains vertical LOP's without need for costly-complex "spherical" corrections as shown in Figure 1. We are not suggesting a new navigational system, but a well planned integration of the two existing systems so that the benefits of each are derived to create what might be considered a third system (VOR-Omega or "VORMEGA"), but one that seems to offer much more than either system alone. The combination for general aviation is much more suitable than competitive techniques, such as CAS, satellites, multilateration, etc.

Furthermore, the cost (a very critical criterion to general aviation) seems to be much less than "extrapolating" the VORTAC for general aviation. The cost of combining the VOR-Omega units in the typical general aviation aircraft to provice universal Area-Nav coverage will possibly be only ¼ as much as with VORTAC equipments, assuming we cater to the lowest stratum of general aviation economics.

SOME SPECIFIC EXAMPLES OF THE VOR/OMEGA INTEGRATION FOR BROADCAST CONTRO

Figure 2 shows an example of a single VOR station with the various lines of position derived from a typical VLF (wide base-line) system. The enormous literature available on Omega will show why so many LOP's in different directions can be derived from even a few stations (see reference 8). In example A of Figure 2, we see LOP-3 derived from VLF pair A-B; in example B we see the

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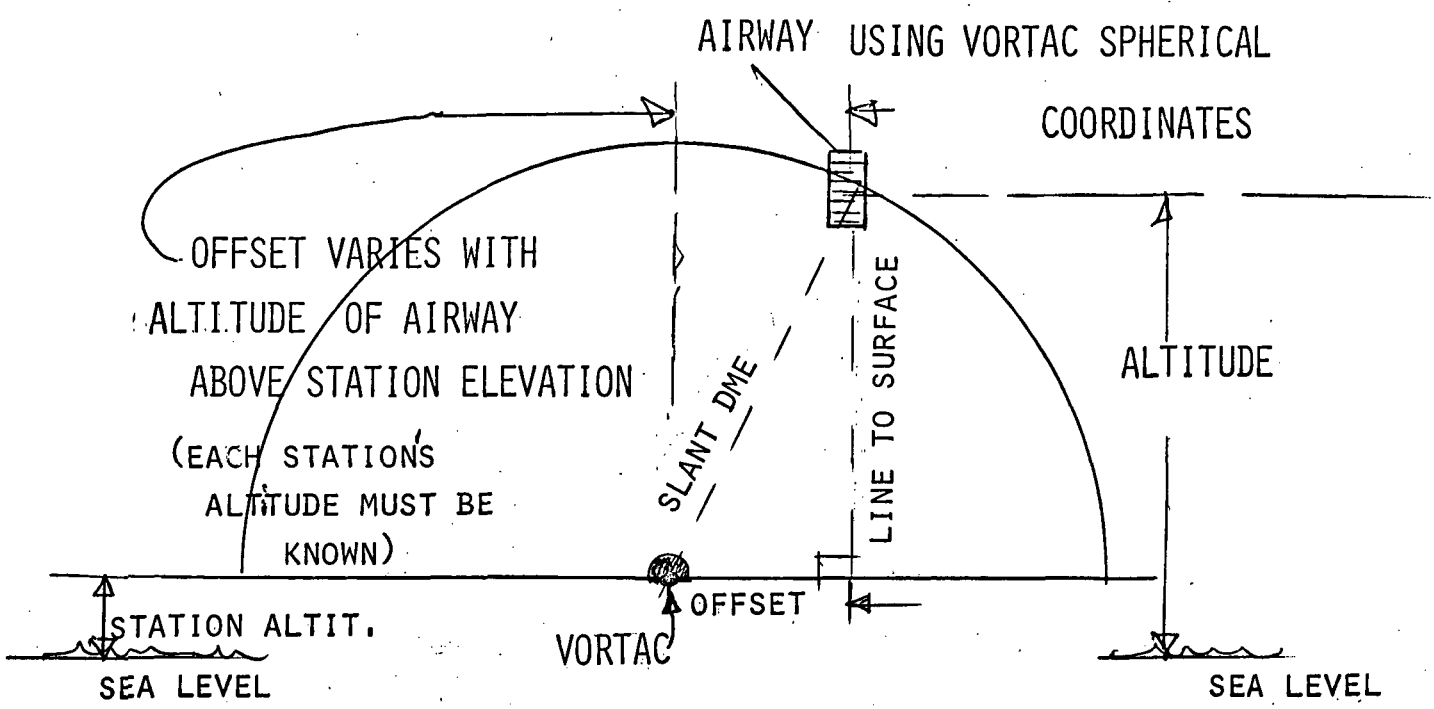
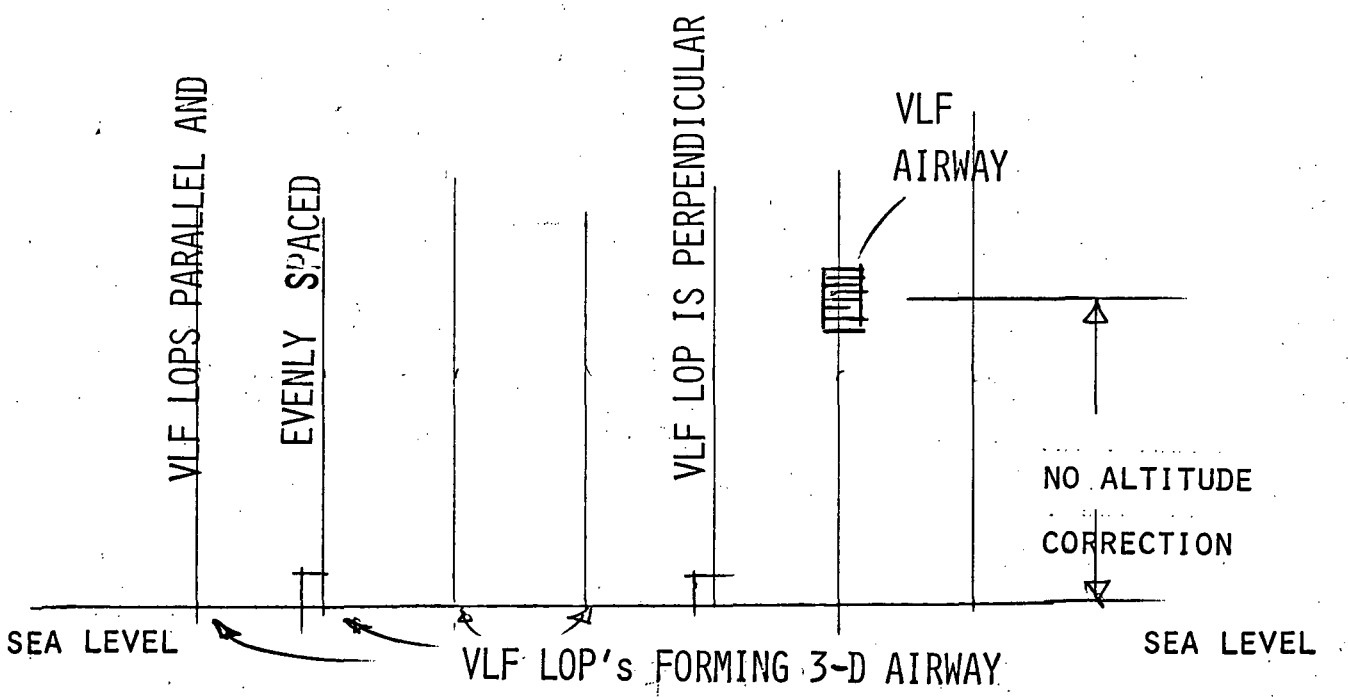
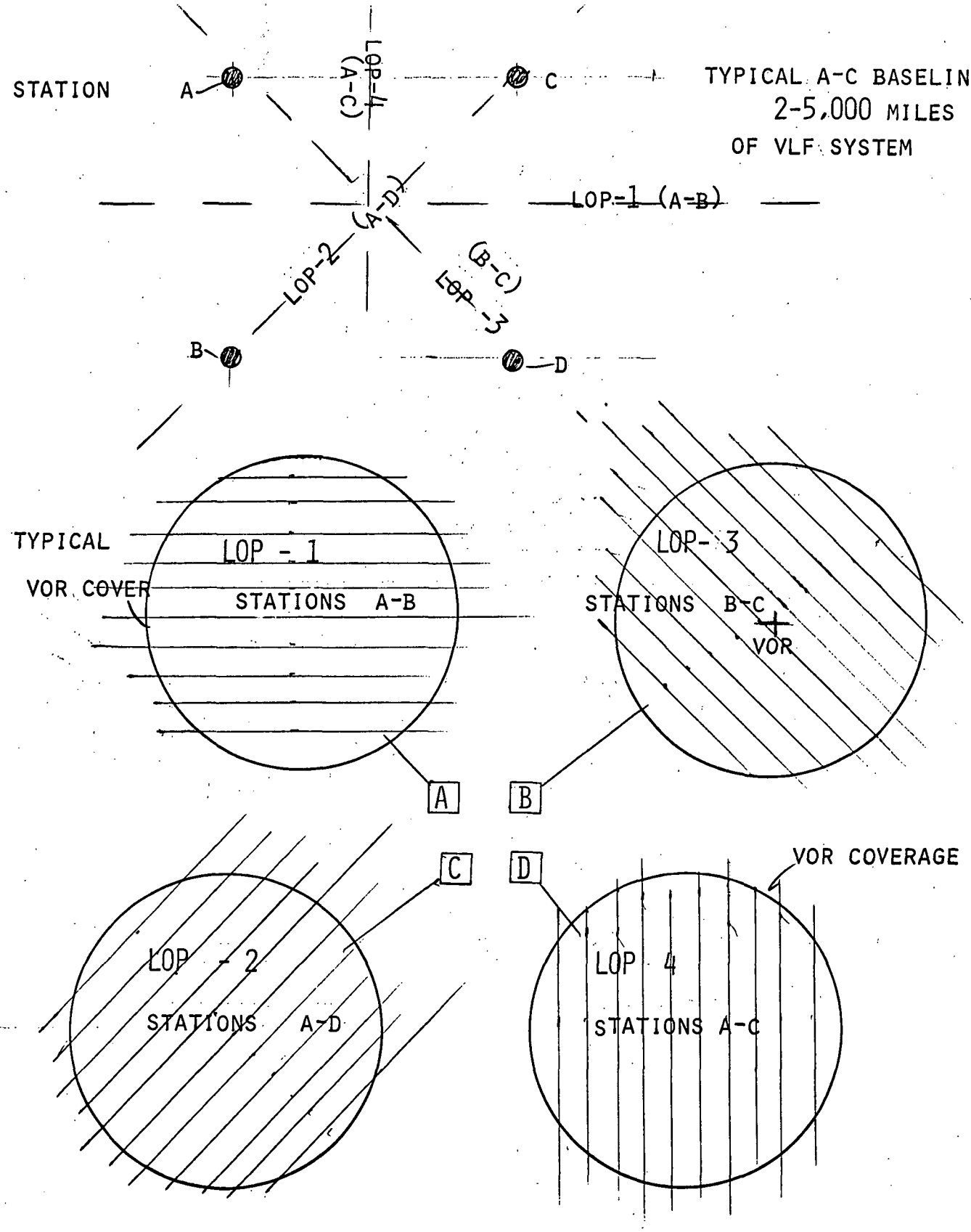




ADVANTAGES OF VLF'S VERTCIAL ,PARALLEL LOP'S OVER SPHERICAL (AND RANDOMLY LOCATED) COORDINATES OF VOR

FIG 1



DIRECTIONS OF VLF (OMEGA) LINES OF POSITION IN A TYPICAL VOR COVERAGE DIAGRAM NOTE ALL LOP's FROM A GIVEN PAIR ARE PARALLEL IN THIS AREA.

FIG 2

LOP-2 derived from VLF pair B-C; and in example C we see LOP-2 derived from A-D; etc. It will be seen that even if "raw" LOP data is used, many simple and highly useful combinations for "mixing" VOR and VLF coordinates exist.

Although it is relatively easy to use two VLF coordinates (crossing obliquely) to create a third set of coordinates in space, we will first examine the rudimentary combinations of VOR and Omega in their simplest form. Furthermore, it is a basic concept that may find acceptance because of its extremely low costs, and also one that does not conflict with other users employing more sophisticated equipment.

As we have seen in Figure 2, we can have the selected VLF LOP's in any of several directions, within the coverage of a single VOR station. From an analytical view, this is equivalent to having 4 "Victor" airways emanating from a single point (in VOR), but with a most significant exception, that we now have 4 airways emanating from any point we choose. This is a key point worthy of further explanation.

In Figure 3-I we see (at the center of VOR coverage) the typical origin of a "Victor" airway at point A, which is the station or center of the circle for VOR coverage. Although VOR/LOP-1 is shown at 180 degrees to VOR/LOP-2, it is possible to establish these VOR-LOP tracks (today's airways) at different angles. However, in every case the VOR-LOP must pass through point A. This is to say, in a VOR/Victor airway configuration for ATC purposes, all airways must pass through point A, which is a most degrading and limiting factor in traffic capacity, creating enormous loads

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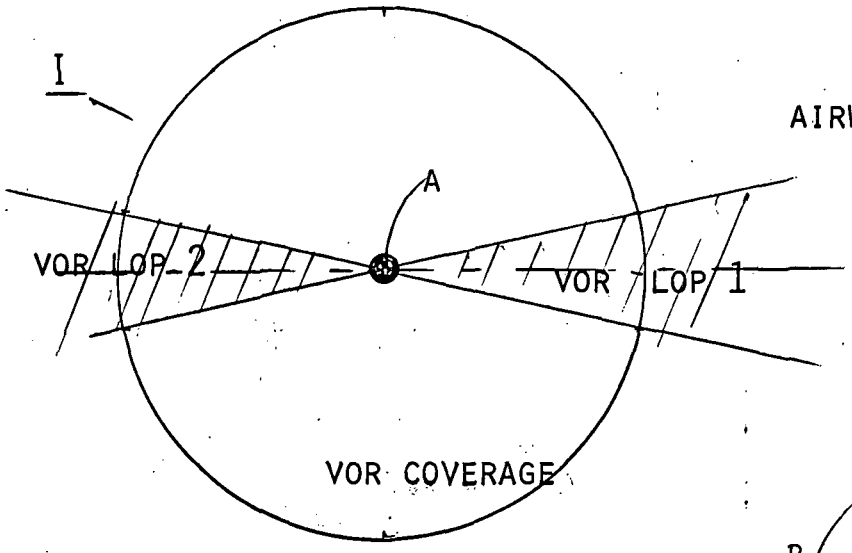
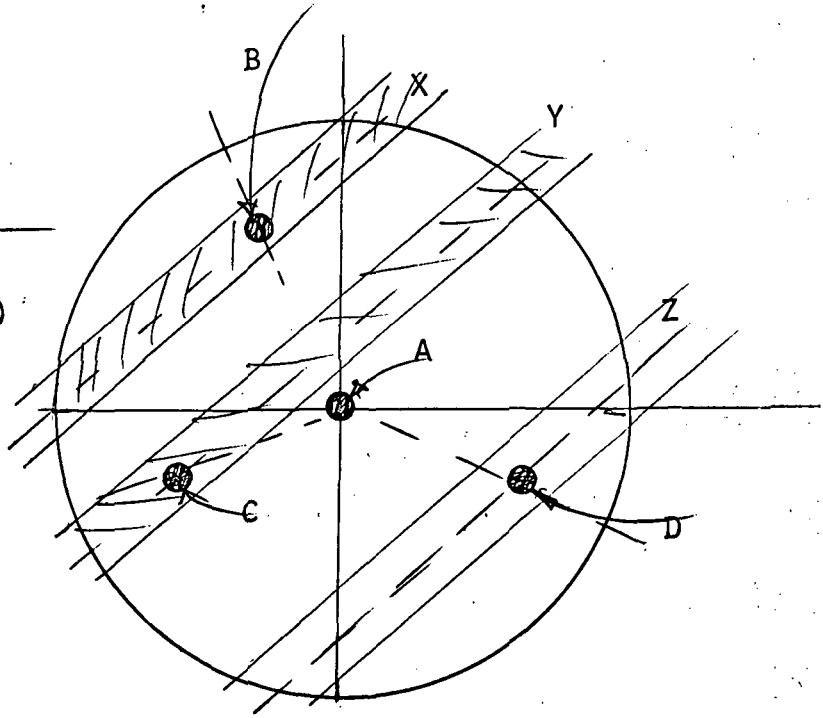
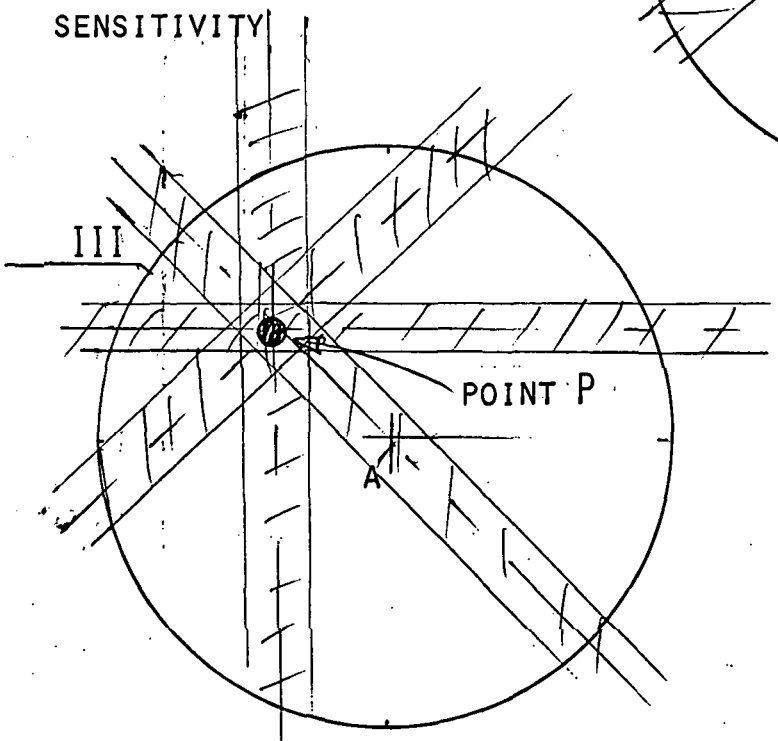


AIRWAY BASED ON VOR/LOP MUST PASS THRU POINT A AND HAS NON LINEAR SENSITIVITY



AIRWAYS BASED ON LOP-2 (VLF) PASSING THROUGH POINTS B, C, AND D WITH CONSTANT SENSITIVITY



OPTION OF AIRWAYS PASSING THROUGH POINT D USING VARIOUS VLF/LOP'S

EXAMPLES OF AIRWAY LOCATIONS IN A VOR COVERAGE DIAGRAM
FIG 3

on control of air traffic converging on point A that is unwarranted by the actual numbers of aircraft in the coverage diagram. No flexibility exists in the service area of a VOR airway.

Furthermore, if it is desired to have several airways at many different LOP's, then they all converge at point A, creating traffic congestion, high risks of collision, and put unnecessary stress and workloads on both pilots and controller in dense traffic environments. To add insult to injury, seldom does point A lie near the origin of the flight, the destination of the flight, or even on a line connecting the origin and destination.

In Figure 3-II we now see points B, C, and D that are created by our combined VOR/Omega concept of airways. We see, for example, point B traversed with Omega LOP-2 (from Figure 1). We have created a nearly constant width airway passing through point B and not point A. Also note that check points on the airway (X, Y, Z in Figure 3-II) are provided by the VOR radials so that no ambiguities exist. Being in the coverage of the VOR signals, the pilot uses the automatic voice recordings transmitted on the VOR that are controlled by an Omega "differential signal." A single Omega receiver in the area (100 X 100 miles or so) provides on the telephone lines to the voice channel of the VOR ground station the local VLF-diurnal correction. Also transmitted is other VOR-voice (automated) information suited to Broadcast type of ATC and airway scheduling. Using the VOR/Omega combination coordinates and communications functions, a dispersed, high-capacity, low-cost ATC system for general aviation is available, based on Broadcast control of that class of airspace user.

Thus, a pilot starting at point P or passing over point P on a direct flight is not forced to pass over point A as noted in Figure 3-III. It is as if we had the equivalence of a Victor airway system at nearly any point in the coverage of the universal VLF signals that fall inside the circle. That we could have an airway in many possible directions designated through any service point, such as a small airport. Furthermore, the error that increases with distance along a VOR airway is avoided since the actual right-left indication the pilot uses is the constant sensitivity VLF (Omega-type - signal). The VOR is important, however, as it is used as a (1) back-up, (2) differential data source, and (3) as a cross-track fixing device or "waypoint" indication (more on "waypoints later).

It will also be seen in Figure 3-III that other points, such as C and D, can be serviced by this new, multi-direction airway concept, thus avoiding air traffic from concentrating at point A, and most importantly, from flying unnecessary distances creating delays, ATC loads, and convergence by being forced to pass through point "A" (as all Victor airways now do).

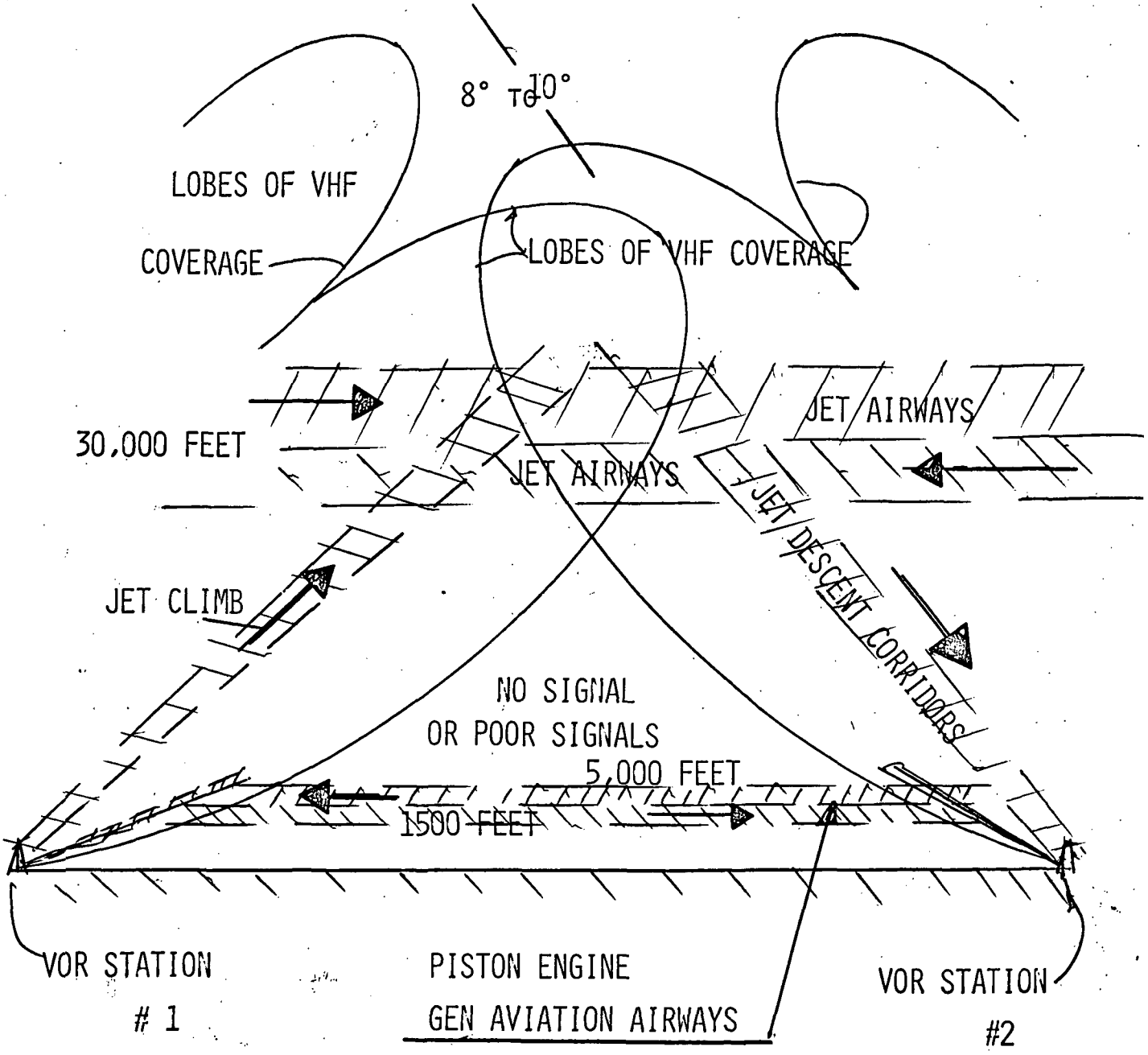
In Figures 3-III and 3-II we see that the other LOP's of the VLF system each pass through points B, C, and D, just as they pass through point P, giving a choice of airway direction at these points. Again, this is nearly the equivalent of a VOR with 4 to 6 airways identified at each of these points. We have shown in Figure 3 an example of 3 points, other than point A, that can be served with 4 bi-directional airways each, or 12 bi-directional airways. This example can be expanded to cover perhaps 20 service

points, each with the capacity of originating airways from that specific point. Or, an airway can pass through these additional points.

This clearly shows that the area of the VHF signal coverage is now utilized much more fully than in the radial-only concept of VOR that most of general aviation seems restricted to because of high costs of VORTAC-R-NAV. The airways depictinn in Figure 3-III are generated at much less cost than the addition of DME, R-NAV computers, altitude corrections, and complex coordinate conversions and charting of VORTAC-Area-Nav.

As we will stress later, the airlines already seem committed to VORTAC-Area-Nav since the cost to them is small relative to their airframe and revenue generation capacity, but will probably remain excessive and overly complex for general aviation (the nearly 200,000 aircraft in the lower 85 percent economic strata thereof). This potential of VORTAC-Area-Nav use by airline and other jets (business jets) is commensurate with their economics, flight profiles, and cruising altitudes as suggested in Figure 4. Business jets will outnumber airline jets by about 3 to 1 in 1980.

There tends to be a natural traffic segregation by aircraft types and flight performance (suggested in Figure 4). With VOR-Omega use by light (piston) general aviation aircraft and VORTAC-Area-Nav use by jets (business, DOD and airliners), there would seem to be a harmonious relationship of airspace assignment, radio propagation advantages, cost advantages, and user's benefits optimized in each case for these widely divergent users of the national airspace.



VERTICAL COVERAGE OF VORTAC SYSTEM IS MORE SUITED TO TYPICAL JET AIRCRAFT OPERATIONS OF CLIMB, CRUISE AND DESCENT THAN TYPICAL GENERAL AVIATION PISTON AIRCRAFT OPERATIONS AT LOWER ALTITUDES.....

(NOT TO SCALE)

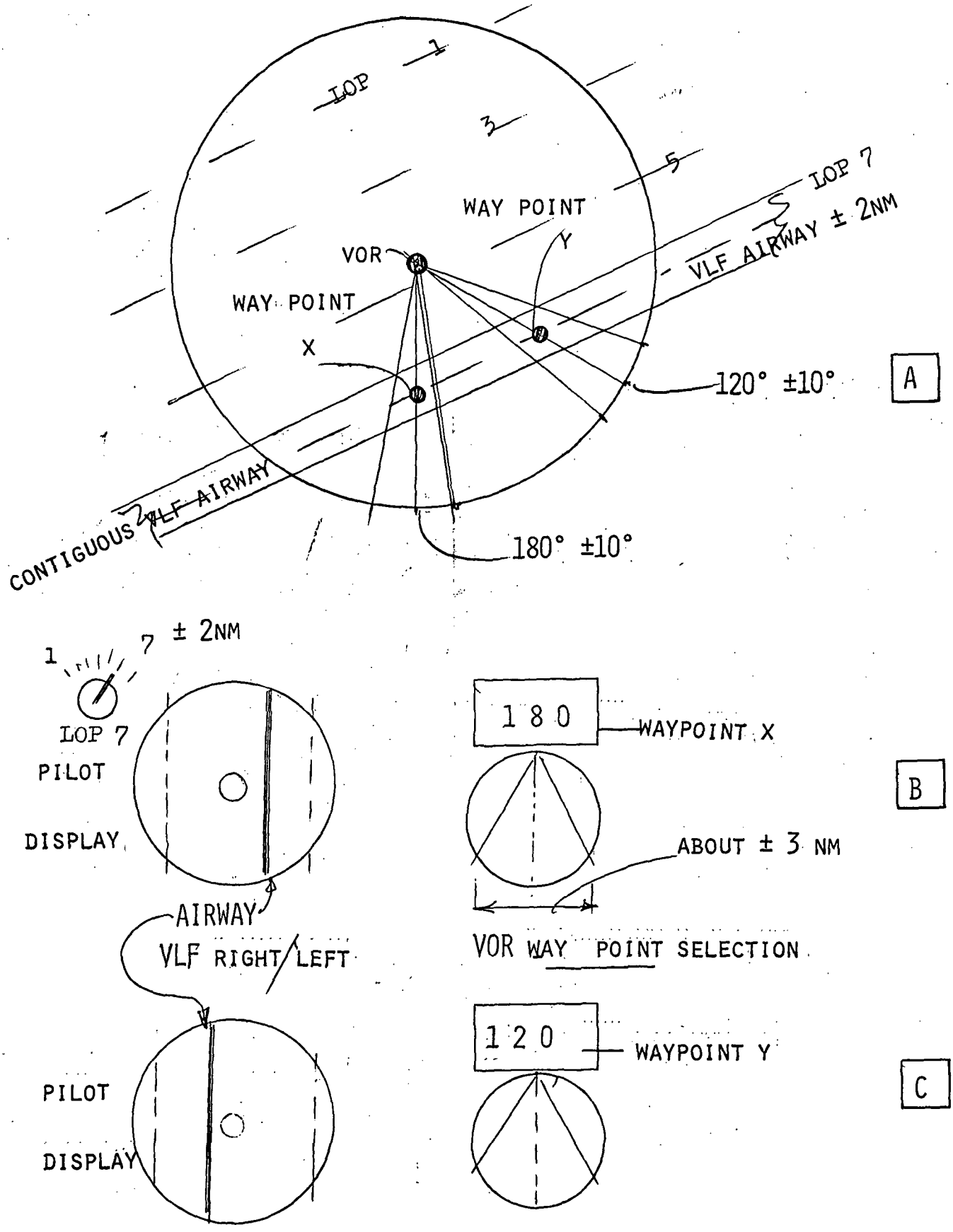
FIG 4

This large cost and operational gap can best be filled by the separate use of (1) VORTAC and (2) VOR/Omega airways without serious problems of regulations, administration, or charting, etc., since VOR would be common to both schemes and 1,000 such stations already exist. This VOR/Omega concept may appeal to many, while an "Omega-only" concept may not seem as attractive since airway conflicts might be created. A true integration of both types of airways and ATC concepts is possible using VOR as a common element in both concepts. Low-cost use of vast new airways with Broadcast control techniques would be frustrated if only VORTAC-R-NAV is available and VLF's potential is not exploited.

It is highly significant that the VOR/Omega marriage does not deny VORTAC-Area-Nav, nor does VORTAC-R-NAV deny Omega/Area-Nav from development on their relative merits and satisfaction of diverse users' needs. It is a way for technically, politically, financially, and operationally making use of the nearly 50 percent of the National airspace not now usable because of deficiencies in the airway structures, and to offer an airway emanating from every runway of every airport in the nation regardless of its size, location, or direction.

EXAMPLE OF PILOT USAGE OF OMEGA/VOR SYSTEM OF AIRWAYS--"VORMEGA"

In Figure 5 we see a simplified case of one VLF (Omega-like) LOP crossing the circular signal coverage diagram of a VOR station with its radial lines-of-position. That is, we have two coordinate system overlapping radials and parallel lines-of-position. Let's assume the pilot wants to go from point X to point Y in Figure 5. Looking on his airways charts, he sees the radial (compass-card)



COMBINED USE OF VOR AND VLF (OMEGA) FOR WAYPOINT, DIURNAL CORRECTIONS

FIG 5

enscribed as on current charts and, in addition, a series of parallel and numbered LOP's overlaying the radial coordinates.

He sees, for example in Figure 5, that VLF LOP No. 7 passes through points X and Y. Assuming he departs point X, he obtains (by tuning to the VOR station) the differential setting for the VLF signal eliminating any diurnal errors since the differential corrections are given by automated voice reports every few minutes. A significant diurnal change usually takes a quarter hour or so. He sees shortly after takeoff the crossing LOP radial of the VOR that he is at a point on his flight path (that is a designated airway) between X and Y. In Figure 5-B we see his display; the right-left indication of the LOP-7 gives him a linear error presentation on either side of the airway centerline.

This VLF airway sensitivity is typically ± 2 NM, according to some experts who have some experience flying this type of VLF airway, but it can be any value from about ± 1 NM to ± 4 NM. Importantly, in all cases the airway width will have a constant sensitivity and linearity of his flight path deviation indication. This infers that the pilot can, if desired, fly off the airway but exactly parallel to it, say, to descend into an airport with great ease. This is something impossible with a VOR-only Victor airway deviation display, and this great potential of VLF, precision-offset flight is of great significance to ATC procedures.

We now see that the VOR display is used as it is now installed. By turning the radial selector to his first checkpoint (R-NAV waypoint), which is shown as X and is a cross-bearing of 180 degrees in Figure 5. Since the VOR indication (full scale to

full scale) is normally about ±10 degrees, we have an excellent display of (1) anticipating the closing to and arrival at the waypoint or checkpoint, (2) its exact location, and (3) the passage beyond it. If, for example, the tangential distance of track 7 (VLF) is about 18 NM from the VOR station, then the ±10 degrees is equivalent to about ±3 miles on either side of the waypoint X.

Next, the pilot continues with ATC concurrence on the track (airway) and is next desirous of arriving at waypoint Y, which for purposes of explanation could be a radial of 120 degrees. Again, the VOR radial displacement indicator is shown in Figure 5-C, and we note that the pilot will have again an anticipation signal about 3 miles (maybe 4) from the waypoint; and exact indication of the waypoint and then his distance beyond the waypoint. Obviously, airway charting would establish these waypoints, but the pilot workload is kept minimal, possibly half of that using VOR-only techniques.

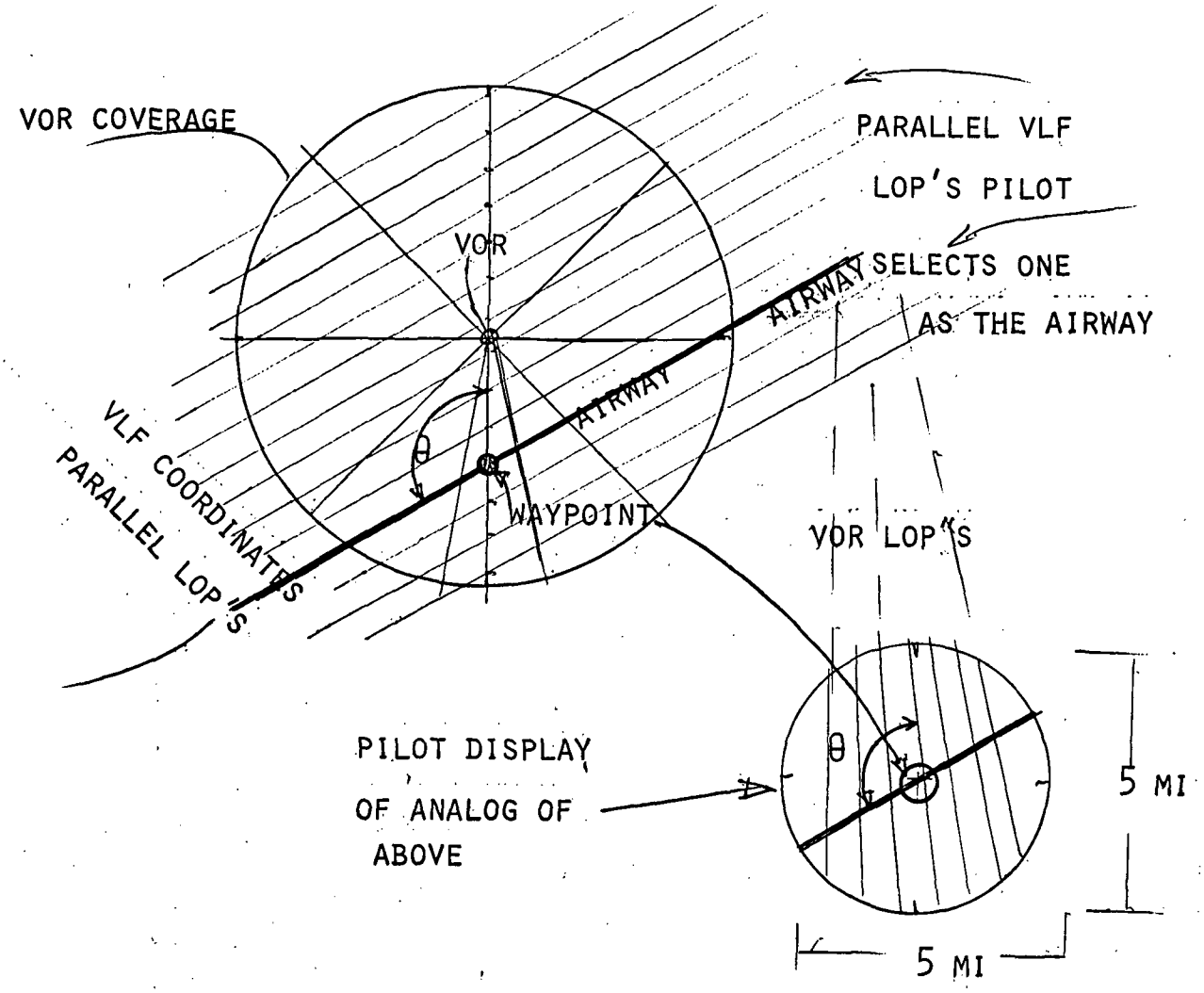
PILOT WORKLOAD USING VORMEGA (VOR/OMEGA COMBINATION OF AIRWAYS)

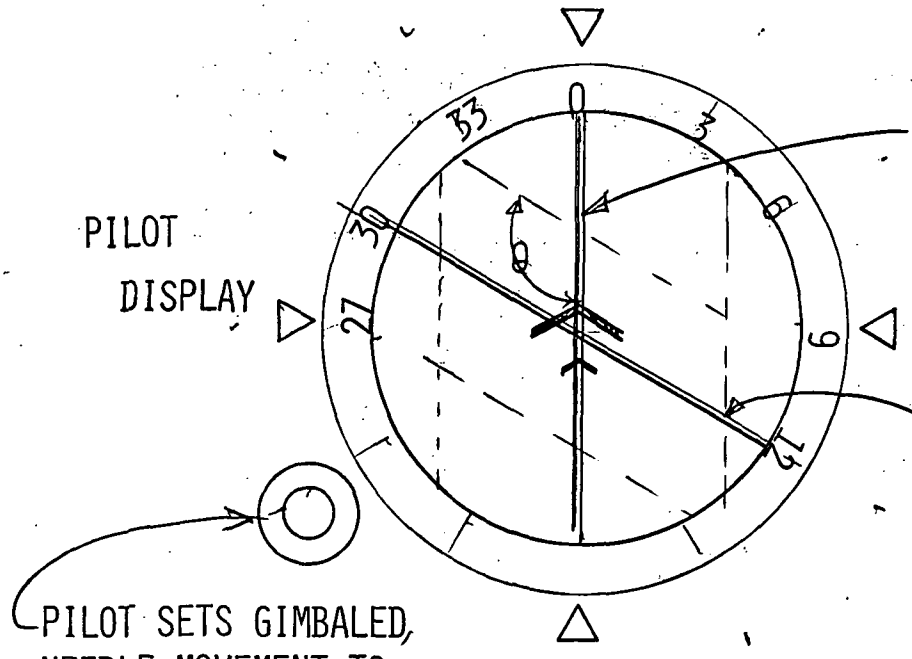
Essentially, the pilot has a contiguous, easy to fly path displayed to him on his airway deviation indicator. Since the airway itself is a VLF origin (2 stations about 4,000 to 5,000 miles apart), it stretches for hundreds of miles without pilot adjustment. It is for 100 miles straight-through/for practical purposes, but with a long curve of parallel lines when examined over a stretch of, say, 1,000 miles. Since waypoints are usually less than 100 miles apart, the pilot has a very low workload, having once selected his airway (No. 7 above using LOP-2 of stations A and D--Figure 2). Next, he must set-in his waypoints using his VOR receiver. This is less

demanding than using a single VOR receiver for obtaining dual VOR "fixes" for crossing VOR bearings (wherein one is lost while the other is being measured). This is to say that the pilot leisurely sets up his next waypoint, sees it arrive in the window of the VOR deviation indicator (Figure 5), pass when it is zeroed, etc. (giving him anticipation, indication of exact passage, and distance beyond the waypoint).

Next, he leisurely tunes the bearing selector of the VOR receiver to the next waypoint, which is another VOR bearing crossing the (unmodified) VLF settings. Thus, at no time does he modify or lose his actual airway-track deviation indication while obtaining a "cross-fix" or waypoint. The pace is slow so that a single pilot in a typical light aircraft at its usual speed should have less workload with "VORMEGA" airways than with VOR Victor airways, or VORTAC with R-NAV airways.

Although it would seem simple to use the two separate displays, as shown in Figure 5 and described herein, a combined display of VOR radials and a linear deviation indicator might be helpful so that one would have sort of an "area" display showing the analog of the localized area surrounding the waypoint (in the center of the display). In Figure 6 we see that this is readily displayed with only slight distortion so that the pilot can use the 4 X 4 miles (or 6 X 6 miles) of displayed area for, say, a turn, descent into an airport, maneuver onto a new airway in another direction, or to a new waypoint, etc. It is obvious that these two display methods and similar ones will require some actual simulator and flight test measurements to optimize them.





THIS NEEDLE DEPICTS
RIGHT/LEFT OF AIRWAY
REPRESENTS VLF LOP

THIS NEELDE DEPICTS
ABOUT ± 3 MILES OF WAYPOINT
(GIMBAL MOUNTED)
REPRESENTS 2DVLF LOP OR A
VOR LOP AS SUGGESTED ABOVE

PILOT SETS GIMBALED,
NEEDLE MOVEMENT TO
ANGLE θ BASED ON VOR LOP
AND VLF LOP

PILOT DISPLAY INTEGRATES VOR/VLF(OMEGA) AIRWAY DATA
FIG 6

However, as in most instrumentation of Area-Nav concepts, the specific form can vary in order to meet acceptable cost levels, pilot requirements, operational needs, etc., without changes in the basics of the concept.

In fact, if the concept of marrying Omega and VOR was not adaptable to at least two to three forms of conventional instrumentation (at different cost and workload levels), it would be a weakness in the concept. Constraining the success of an ATC concept to a single, unique (and possibly costly) pilot display technology is a sure way to assure minimum usage and inability to get a national acceptance. Different engineering concepts and manufacturers will prefer various forms of displaying the new VOR-Omega concepts of Area Navigation. Some of the current R-NAV displays in the low-cost brackets would be good candidates for the VORMEGA display.

AIRLINE USE OF AREA-NAV BASED ON VORTAC AND BAROMETRIC CORRECTION

The above discussion is aimed mostly at the 85 percent light aircraft population of general aviation that will number nearly 200,000 by 1980. The recent national conference on VORTAC Area-Nav and Inertial Area-Nav showed that enormous interest in the subject exists among pilots, engineers, administrators, etc., with over a thousand experts attending a two-day FAA symposium on the subject. Several references indicate the advanced stage of airline thinking on this subject (references 1, 2, 3, 4) Several manufacturers have developed R-NAV computers that cost several tens of thousands of dollars, and fit the VORTAC inertial interface.

References 1, 2, 3, and 4 from the "R-NAV" (Area-Nav) symposium provide a good review of the airline and FAA plans. Considering the emphasis and needs of airlines and the quite different cost-benefits criteria between a 15-million-dollar jet and a 15-thousand-dollar light aircraft, it is likely the airlines will proceed to use VORTAC-Area-Nav in the near future. Reference 2 notes that the various levels of sophistication in R-NAV (computers only, not VOR, DME, etc.) are Mk I, 15,000 to 30,000 dollars; Mk II (includes a digital computer), 40,000 to 80,000 dollars; and Mk III (expansion of inertial-VORTAC interface), 110,000 to 150,000 dollars. Considering the savings in routing, pilot workload aspects, need for vertical navigation in airlines, and worldwide needs (inertial and other coordinates besides VORTAC) can be processed by Mk II and III, these cost figures are not inconsistent with the worth of this service to the airlines.

From the view of the lower 85 percent economic strata of general aviation aircraft (about 200,000 aircraft in 1980), even the simplest Mk I unit is beyond the reach of the user. Many other demands on his resources for ATC, such as transponders, altitude reporting in 1975, PWI, MLS, data communications, etc., are of equal significance to these potential users as R-NAV. They cannot afford all of these new avionic systems and will accept voluntarily only those where the benefits outweigh the low costs (such as the 50,000 transponders costing in the 600 to 1200 dollar category).

This is the main message contained herein; it is possible to encourage these users, who may make up half the airborne aircraft in 1980-1990, to use Area-Nav of the VOR/Omega type since only a

VLF receiver about the cost of a VOR receiver will be added--perhaps in the 1 to 2 thousand dollar level when production approaches the VOR volume.

GENERAL AVIATION AIRWAYS AND AIRLINE AIRWAYS

From the above it is possible to postulate the use of VORTAC by the airlines. It fits their flight profile as seen in Figure 4 where the climb and descent profiles to high altitudes are more commensurate with the vertical lobe structures and signal coverage of the VHF line-of-sight system of VOR at about 100 MHz (and DME at 1,000 MHz). To the side and parallel to these airways can be defined new airspace for general aviation use that is authorized for the exclusive use of certain classes of slow, low-performance aircraft operating below (about) 10,000 feet. From this airspace is excluded the jet aircraft because of its speed, climb corridors, and other differences. Where reference 2 notes the difficult pilot workload in setting in and using waypoints in a jet airliner, these same problems are much less severe in a light, slow, general aviation aircraft (say a light-single). With speeds differing by about 4 to 5 times, the pilot must reset, retune, etc., much more frequently in a jet, and thus the high workload exists.

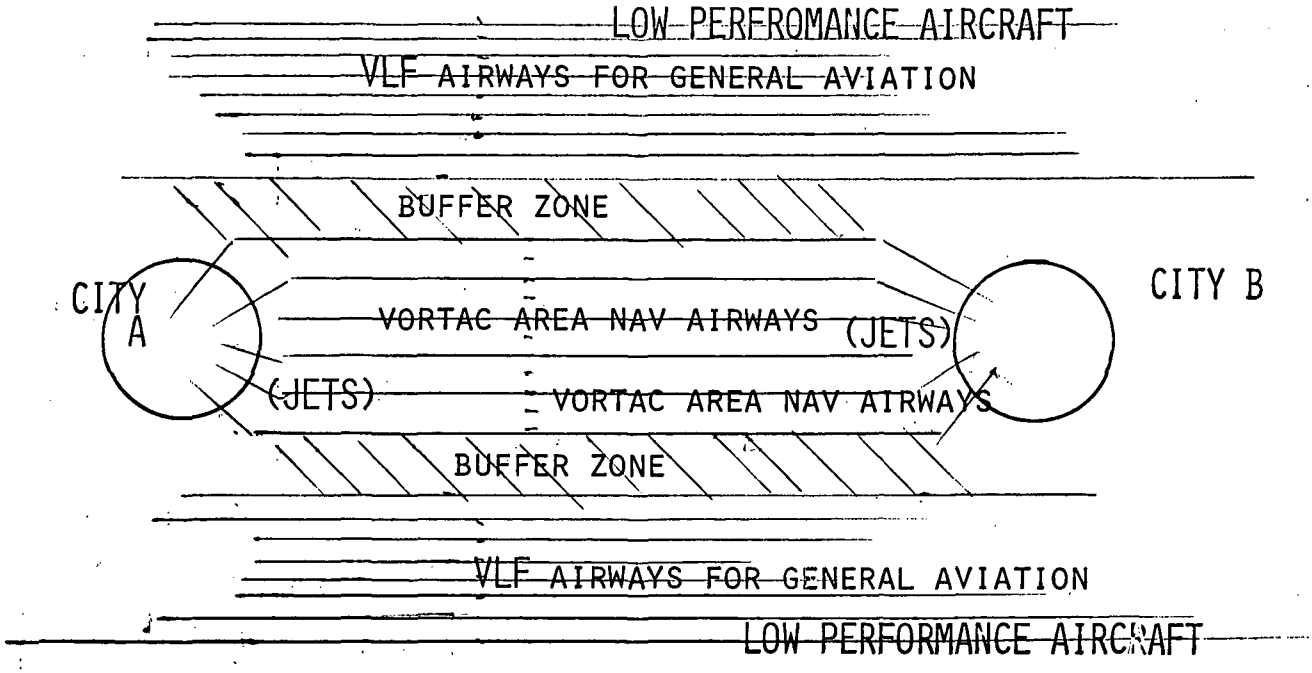
Also, the jet cruising at 30,000 feet needs "vertical" navigation, complicated inputs using three-dimensional VORTAC data from several VORTAC's and barometric altimeter inputs. This is complicated and costly but nevertheless essential to jet operations to gain fuel efficiency and speed in cruise conditions on a direct R-NAV airway where dozens of VORTAC's are involved. This is something the light-single does not need. Thus, many of the assessments

by airline engineers of R-NAV do not apply to general aviation, and their pioneering effort indicates the price is suited to airlines but beyond 90 percent of general aviation aircraft. If airlines hope to conform to the VORTAC-R-NAV airways, as FAA now sees them in reference 3, it will be essential to find new airspace for general aviation.

It is, therefore, suggested, as in Figure 7, that about 8 miles beyond the jet airways and at altitudes well below them, a general aviation airway system be authorized using the two national (funded and existing) systems (in 1974) of VOR and Omega. Each requires no added channels, no new transmitting channels, and are used with simple receivers, each costing about 800 and 1500 dollars respectively, but perhaps nearly doubling the amount of useful airspace on a national basis to general aviation.

The concept of VFR flight anywhere is rapidly vanishing, if not already extinct. So many controlled areas (volumes) of airspace exist that merely excluding a party from them are no longer safe since they are so numerous and geometrically complex in their (3-dimensional) authorization and identification. What is needed is a new airways approach to the use of vast amounts of unused airspace, so it is defined in three dimensions, for general aviation use, and for segregation of high and low performance aircraft which, when mixed, seem to be the major source of mid-air collisions and air traffic congestion.

VLF signals can reach to any altitude of concern to the (piston) population of general aviation as well as being available on the surface, allowing a new concept of pilot usage--ground calibration



JET TRAFFIC USES VORTAC AREA NAV AIRWAYS TO SERVE JETPORTS IN CITY A AND JETPORTS IN CITY B

LIGHT AIRCRAFT (LOW SPEED, ALTITUDE, COST) UTILIZE VLF AIRWAYS ESTABLISHED PARALLEL TO JET AIRWAYS. VLF SERVES HUNDREDS OF OUTLYING AIRPORTS AND LOW ALTITUDES

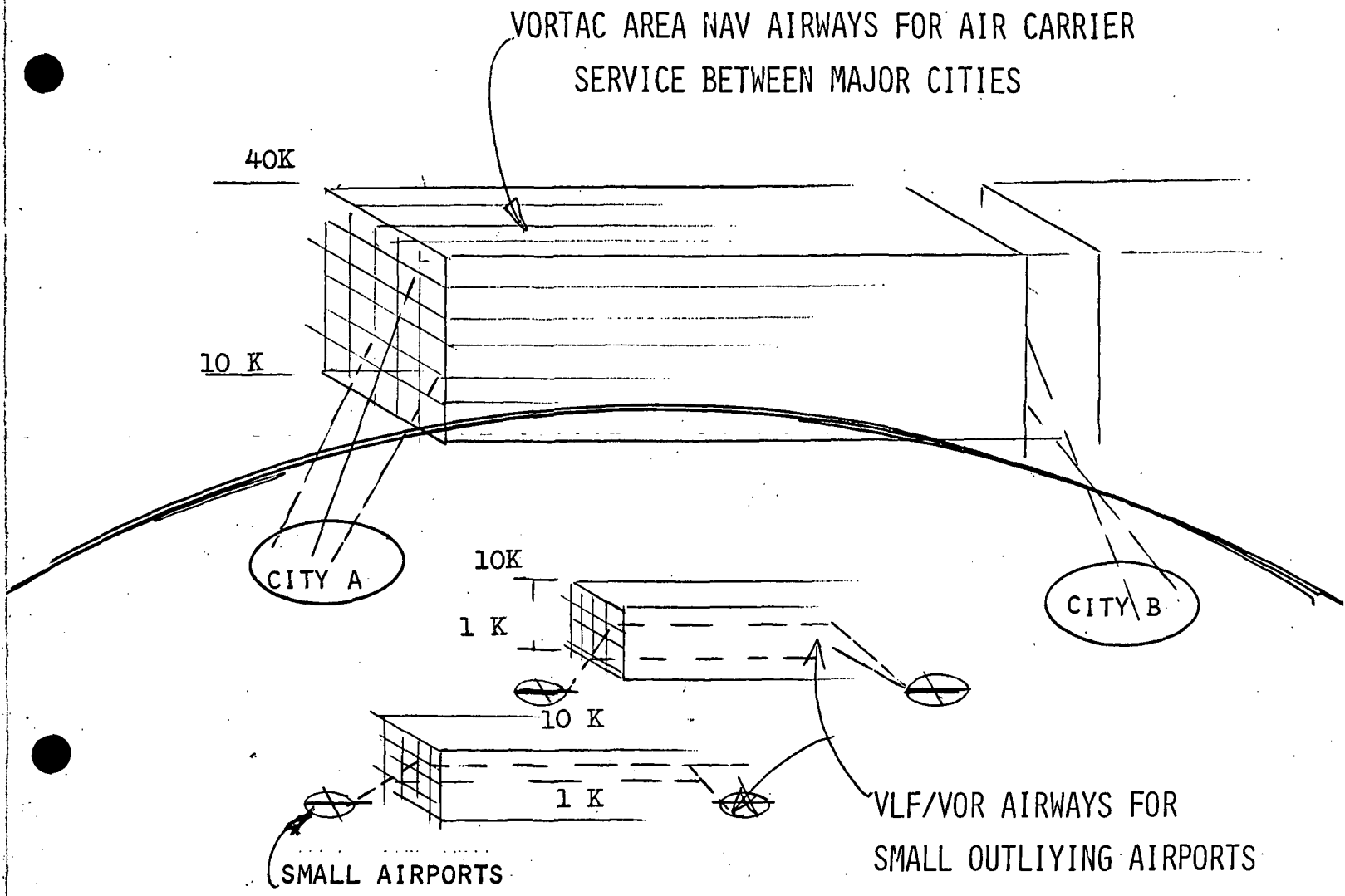
UTILIZATION OF VLF AND VHF AIRWAYS FOR HIGH AND LOW PERFORMANCE AIRCRAFT.

FIG 7

using the actual airway signals just prior to takeoff--something impossible with VOR. This characteristic of VLF propagation adds credibility to the concepts of "Broadcast Control" since the pilot can adjust his climb-airway prior to takeoff and follow it without airborne tuning. By paralleling what some call "VFR Airways" with the VORTAC airways, it is possible to give general aviation a much required service since most of their destinations are increasingly to some other airport than the jetports. For the business jets, he is likely to comply with airways much like airliners, but also will serve the intermediate airports that has poor airways. Figure 8 emphasizes this point.

Admittedly, when the general aviation aircraft is not near the heart of VOR coverage (as the airlines will be since VOR siting usually was predicated on this type of service), we will not have as good coverage from VOR as we might like for the "VORMEGA" concept. However, by integrating Omega with VOR, this weakness is overcome operationally. Omega is available continuously; VOR will be unavailable at times depending upon geography, station location, and altitude of the general aviation airway complex.

Even though intermittent inputs exist from the VOR for the integration functions with VLF Omega, the continuous nature of VLF coverage overcomes this VHF deficiency and yet gains from the benefit of the VOR data when it is available. As was shown in Table I, VOR signals (voice) are used to periodically update the VLF diurnal data; obtain waypoints; assure the two coordinates (VLF and VHF) are tied together; and for a means of exercising some form of very-low-cost yet semi-automated traffic control, based on principles and concepts of "Broadcast Control."



CO-EXISTANCE OF TWO AREA NAV SYSTEMS OPTIMIZES AIR CARRIER USES AND PROVIDES GENERAL AVIATION AIRWAY AND APPROACH SERVICES TO OUTLYING SMALL AIRPORTS: THUS AVOIDING MIXING OF LOW AND HIGH PERFORMANCE TRAFFIC THAT CREATES HIGH ATC COSTS AND HAZARDS..

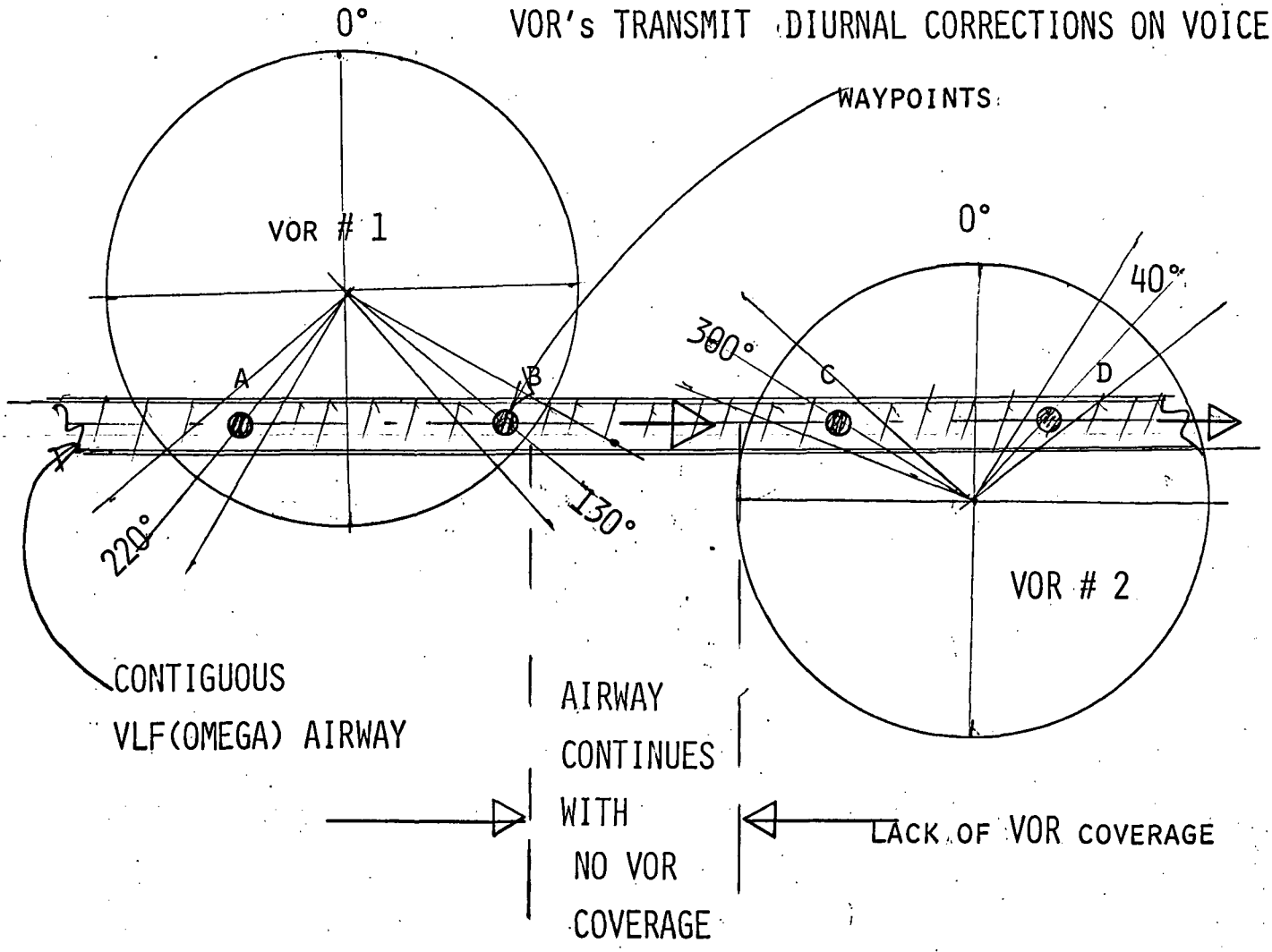
FIG 8

In "Broadcast Control" the pilot follows an authorized VLF/VOR airway as does all traffic going between service points. In doing this, the airway is identified as one of several parallel airways, and one of several altitudes, and are so codified and presented in flight charts and manuals to the general aviation pilots. The airway is then broken longitudinally into "blocks" to attain a three-dimensional block of airspace. Thus, each airway is a series of blocks of airspace defined and coded for pilots in three dimensions.

It will be seen in Figure 9 that the actual centerline and boundaries of the airway are determined by the VLF(Omega) signal. At takeoff the pilot "zeroes out" all VLF errors, knowing the airport location and the fact that the airway starts at the threshold of his departing runway, something we <u>can</u> do with VLF that is <u>impossible with VOR</u> or VORTAC. Next he climbs on an airway that is an extended centerline, avoiding turning (unless occasional other requirements exist, such as a curved noise abatement airway procedure). Next, while enroute he tunes to the VOR signal associated with that specific (VLF-VOR) airway and obtains "cross fixing" data, or what is now called "waypoints" in the new "R-NAV" language.

This procedure has the double benefit of obtaining the voice data on the VOR (simultaneous voice), as well as providing an independent means of establishing the waypoint (which may also be established with VLF since VLF has coordinates that cross the airway obliquely). If a failure in VOR occurs, the pilot continues on VLF; if a failure on VLF occurs, the pilot reverts to VOR usage, holding his heading to the waypoint and then reverting to

NOT TO SCALE



INTEGRATION OF VOR AND VLF(OMEGA) PROVIDES

1- MEANS OF CONTINUOUS AIRWAY TRACK WITHOUT BREAK DUE TO VHF (VOR) COVERAGE LIMITATIONS

2- PERIODIC DIURNAL CORRECTIONS FOR VLF AIRWAY

3-CONSTANT AIRWAY SENSITIVITY AND VERY LOW ALTUDE AND SURFACE COVERAGE

4- INDEPENDENT WAYPOINTS COORDINATED WITH VORTAC AREA NAV

5- LOW COST AIRWAYS THROUGH ANY POINT WITHOUT "3 D"COMPUTER.

MERITS OF VOR/OMEGA INTEGRATION

FIG 9

the standardized VOR navigational procedures. Two linear LOP systems can achieve this complementary and "fail safe" service that a circular LOP (DME) cannot provide with equal utility and credibility.

Although VOR stations are occasionally off the air for various reasons, a more important and irksome failure of VOR service is signal "dropouts" and its unavailability on a contiguous basis. Signal "dropouts" occur between stations as shown in Figure 9. Here the pilot has used two waypoints, A and B, to check his location and to comply with ATC (each segment of the airway is a "block" such as A-B, B-C, etc.). The pilot then dead-reckons longitudinally between the waypoint B and waypoint C where no VOR coverage exists.

This is partially "open-loop" ATC, only for a known time and then only longitudinally, as his direct airway signal is not lost since it is VLF and continuous across the nation at all altitudes. However, for ATC purposes the block B-C, even without VOR coverage, is treated the same as block A-B; that is, occupancy is not permitted by another aircraft until the first aircraft clears past waypoint C, which by that time is in VOR range of station #2. Upon returning to station #2 the pilot acquires waypoint C and "anticipates" the passage the last 3 miles using deviation indications as shown previously in Figures 5 and 6. He also acquires a new diurnal (differential Omega) input from the voice data on VOR-2. Since the pilot may now have travelled some 100 miles from the original diurnal input, time and location has modified his "differential" Omega input; it is now updated. Once this new

"differential" data is used to update the VLF reference for the coverage area of VOR-2, the pilot proceeds to waypoint "D", etc.

Importantly, the VOR data will serve as a cross-check on the VLF-longitudinal-LOP data since both sources of waypoints are used. The pilot essentially has a continuous back-up on waypoint data in the dual low-cost and simplified use of the VOR and Omega coordinates.

Since so many small airports will never have an ILS or even an airway near them in the current VORTAC concepts, this technique of a second Area-Nav system for general aviation offers needed service and Broadcast Control of air traffic to some 10,000 such small airports. With an airway structure that is much easier to use in the cockpit and much safer than VORTAC alone, back-ups and "co-monitoring" of both systems occur in their usage, giving pilots confidence in their use and/assuring him that the weaknesses of each alone (Table I) do not deny safety. The workload is much less for the general aviation pilot since the VLF airway is initially aligned with the departing runway, and signals reach the departure climb from the beginning. Similarly, the arriving runway is served without the complexity of divergent approaches and the high risk of "VOR let-down" that has now been identified as one of our major accident sources (see NTSB paper by Reed at the Symposium on Area Navigation in January 1972 and the ICAO Bulletin of December 1970, "Accident Prevention," where it is noted that 72 percent of fatal accidents occur during an instrument approach). The Dangerous "Circling Approach" will be a thing of the past with the adoption and use of "VORMEGA".

BROADCAST CONTROL USING VHF-COM AND VHF-VLF AREA-NAV

The pilot using a low-cost tone data signal (a 100-dollar unit paralleling the microphone input to his VHF-COM set) solicits the ground regarding the occupancy of the next adjacent airway block, as in Figure 9. If the block is unoccupied, the aircraft (via a decoded automated voice message, much as the telephone company uses for time signals) clears the aircraft. The voice and timing also confirm the aircraft's identity. Any further requests for the specific block will be denied until the aircraft clears the airspace of the airway block by another pushbutton selection soliciting authorization to enter the next block of airspace.

Two nearby pilots can actually hear each other's instructions and aid in air-to-air supervision. This is one of the important precepts of Broadcast Control. The ground system is a simple and low-cost relay-electronics; interlocking assignments is a system that is a relay analog of the airway. Possibly a "mimic-board" placed at the (FSS) Flight Service Stations near the airways would also assist since FSS personnel are used in Broadcast Control.

Thus, the pilot progresses to his destination through sequential airway blocks, and if denied entry into one block, he holds (circles) within his currently assigned block of airspace. ATC radar vectoring is avoided if the pilot navigates and controls under Broadcast ATC rules. This concept of "block signalling" was partially engineered into the FAA airway system (then CAA) in 1948-1952, but became too slow for the much faster turbo jet aircraft. The arrival of the jets forced major changes in ATC,

yet block signalling could now be revived for the much slower, low-flying, light aircraft of general aviation.

A detailed engineering design of such a system is beyond the scope of this report, but the fundamental elements on which it is based already exist in the coverage of the VOR and Omega systems; the VHF-COM network and with multi-tone data reporting from the aircraft. No new technology is essential, but what is needed is a "total system" approach to the problem to optimize on an evolutionary basis what is available today. The concepts of Broadcast Control offer a new means of dispersion of air traffic by creating new airways in airspace not now utilized but essential to the growth and safety of general aviation. Utilization of this new airspace does not now appear possible with VOR or VORTAC R-NAV. The costly application of VORTAC R-NAV to aviation may be accepted by the airlines but is beyond the reach of most of general aviation according to the prices of nearly all VORTAC R-NAV equipments. Two national R-NAV systems seem inevitable: one an airline system based on VORTAC inputs costing from 20 to 100 thousand dollars per aircraft; the second system based on VOR/Omega costing about 2 to 3 thousand dollars in production quantities.

AIR/GROUND COMMUNICATIONS IN BROADCAST CONTROL OF AIR TRAFFIC

In many concepts of ATC such as "radar vectoring" it is essential to convey a great deal of information between the pilot and controller. This infers in many cases a modernization of communications, using an automated data transfer system (often called a "data link"). Currently the FAA is considering a means of adding an "up link" to the SSR transponder system. Such a

ground to air link would complement the current air to ground link coverage of 8,000 codes relating to altitude and identity. A coded message on the up-link of 40 to 60 bits would be necessary to accommodate the address, command, quantity, and parity checks.

This "Discreet Address Beacon System" (or "DABS") is very costly and tends to further emphasize the concepts of "Close Control" where the ground authority commands, and the pilot is little more than a lackey in the system. Such concepts add increasing burdens on ground "automation," remove the enormous value of voice, and increase costs and complexity to a point where nearly all of general aviation is effectively denied such services.

The intent here is to stress the need for a low cost Broadcast Control system that avoids these pitfalls in national planning of airspace usage. A VLF grid, either entirely new (being designed for the contiguous 48 states) or a marriage of existing VPR and VLF/Omega in the 1974 period, is a more likely solution. Both services will then exist across the entire nation and are available for ATC with low cost airborne units. This marriage might be termed "VORMEGA", and we have already identified several advantages and virtues of the concept. Essentially, the weaknesses of each system are overcome when combined to make VORMEGA suitable for a low-cost "Broadcast Control" coordinate system. The strengths of Omega overcome the weaknesses of VOR. The weaknesses of Omega are overcome by certain VOR characteristics. Viewed from the joint applications in VORMEGA, we have two independent back-ups, VOR and Omega that can be used to create linear LOP's separately.

DME is avoided with its complexity, need for costly R-NAV computers, complexity of a multiplicity of spherical coordinates, and lack of linear tracks from DME only (when VOR fails). Effectively, general aviation can be provided a total Area-Nav system in VORMEGA that is universally available across the nation for a small fraction of VORTAC R-NAV. The airlines, because of other large benefits relative to cost considerations, nature of the flight patterns of jet aircraft, etc., may well utilize R-NAV with VORTAC on the nation's high-density air routes. VORMEGA will then allow an alternative since these routes will not use the low-cost VOR "radial tracks."

Denying the VOR radial service on dense airways, we now allow general aviation the use of a much expanded airways-ATC airspace alongside these jet R-NAV routes and relieve loads on them based on VORMEGA. Costing possibly only 20 percent of the VORTAC solution, the airlines and general aviation of all classes comply with a new airways ATC concept.

In any event, Area-Nav--whether based on VORTAC, based on Omega, or based on the VORMEGA concepts--has one goal in mind: placing the pilot back in the ATC loop where he belongs and where he can do specific ATC jobs better than the controller. Much improved tranquility of mind is obtained when flying in separated airways over the concepts of Close Control where some "black box" commands him without his ability to exercise his judgment, establish the credibility of the ATC command, or even be aware of the commands to other aircraft in his proximity.

In Reference 2 American Airlines (AA) reports from a great deal of experience shared by other airlines that the R-NAV's

TABLE II

COMPATIBILITY OF "BROADCAST" AND "CLOSE"
CONTROL CONCEPTS OF AIR TRAFFIC CONTROL

1. AIRLINES AND JETS USE VORTAC, PARALLEL AIRWAYS CREATED BY THE USE OF VOR, DME, R-NAV COMPUTERS, ALTITUDE CORRECTION, AND ABILITY TO DISPLAY VERTICAL AND LATERAL AIRWAYS (3-D)

2. LOWER 85 PERCENT ECONOMIC STRATA OF GENERAL AVIATION WILL USE A COMBINATION OF EXISTING VOR AND OMEGA SYSTEMS WITH GREATLY SIMPLIFIED COMPUTER AND DISPLAY POSSIBLE WITH THE MANY COVERAGE AND "GEOMETRICAL" ADVANTAGES OF "VORMEGA"

3. AIRLINES CONTINUE TO USE "CLOSE" CONTROL CONCEPTS OF RADAR-VECTORING AND POSSIBLE USE OF "DABS"

4. GENERAL AVIATION (2) UTILIZES "BROADCAST" CONTROL CONCEPTS BASED ON GREATER FLEXIBILITY OF VORMEGA AND THE UNIVERSAL NATURE OF ITS COVERAGE FOR AIRWAYS AND NON-PRECISION APPROACHES ALIGNED WITH UP TO 30,000 GENERAL AVIATION AIRPORT APPROACHES.

5. AIRLINES USE HIGH-DENSITY ROUTES BETWEEN MAJOR CITIES AND AT HIGHER ALTITUDES WITH SLANT-AIRWAYS OF CLIMB-DESCENT CORRIDORS FOR JET OPERATIONS

6. GENERAL AVIATION USES LOW-DENSITY AIRWAYS ESTABLISHED BY THE VORMEGA AND BROADCAST CONTROL BASED ON BLOCK SIGNALLING

7. AIRLINES ARE CONTROLLED BY GROUND ATC THROUGH THE TRANSPONDER, R-NAV, GROUND RADARS, COMPLEX COMPUTERS, DATA LINKS, AND THOUSANDS OF CONTROL PERSONNEL AT CENTERS AND TOWERS

8. GENERAL AVIATION TRAFFIC MOVES ON DISPERSED AIRWAYS SEPARATED FROM ITS OWN KIND AS WELL AS AIRLINES, AND DISCIPLINE IS MAINTAINED BY BROADCAST CONTROL. THE PILOT, USING TONE-DATA ON VOICE CHANNELS, SOLICITS AIRWAYS AND APPROACHES WITH LITTLE OR NO GROUND PERSONNEL INTERVENTION

concepts reduce communications by as much as 25 percent and can reduce both the controller and pilot workloads. In fact, AA experience indicates that radar monitoring of R-NAV routes is not necessary, thus off-loading the ATC controller. The pilot, of course, following his displayed 3-dimensional airway to the mandatory reported waypoints, feels strongly that more authority and capability must be restored to the cockpit if we ever hope to solve our ATC problem. Even though individual pilot complaints about R-NAV prevail, it is evident from the recent symposium that they prefer the concept of R-NAV in ATC rather than more radar-vectoring by automated ground computers and data links.

The question remains, however, as to how the pilot will communicate in the new Broadcast Control concepts. Even though the communication load will be less, it is important that modern communication advances also be considered as part of the control system. In our case of general aviation, it is suggested that we consider use of a fully developed new technique in voice communications, such as the dual-tone data transmission system used in the A.T.& T. system. Tone data solicitation from the air and automated, canned-voice messages from the ground avoid the need for a costly airborne data-link receiver.

Where it may cost 50 to 100 dollars for the 4 X 4 dual tone system (one of 16 combinations in a 50-millisecond tone burst) for an airborne unit, the ability to decode up to 4,000, or even perhaps 100,000 tone data messages requires ground equipment that is costly. However, a single ground unit serves up to 50 aircraft, greatly reducing total costs since under the recent "user"

tax the pilot pays for both the air and ground units. Furthermore, we have a firm national commitment (as a part of the SSR-transponder program) to add altitude reporting by 1975 in nearly all aircraft. This is another major means of also sending messages of identity, altitude, position, emergency, acknowledgments, etc., to the ground system, which we may want to apply sometime in Broadcast Control. The SSR is a fully developed system; however, some modest changes in communications are needed if Broadcast Control of a vast new airway capacity is to become a reality.

As noted before, it seems quite possible, using very low-cost VHF-COM capacities already available (but needing organization), to solicit the use of an airway segment between two waypoints. This solicitation is acknowledged by the automated voice from the ground, and the interlocks of a simple relay-type system prevent any other commitment of this R-NAV segment until it is released by the first aircraft. Thus, if an R-NAV segment is assigned and in use, the multi-tone request is denied in "canned" voice. Since the interlocked replies to all solicitations and airway assignments in their local area are monitored by the pilots and the ground and other aircrafts actions are clear (in, of course, low-density airways created by the VORMEGA technique).

Next, once the airways segment is authorized, the aircraft occupancy is assumed until the next waypoint is reached. With the capacity of literally hundreds of parallel airways possible with the basic coordinates and geometrics of a VLF system, airways as closely spaced as VORTAC R-NAV airways are readily possible. For an aircraft to simply request an adjacent segment (to the right, left, above, or below the one occupied), he pushes the

TABLE III

COMMUNICATIONS IN BROADCAST CONTROL
USING INTEGRATED VOR/OMEGA SYSTEMS

FUNCTION	PILOT ACTION
Set Omega Diurnal	a. On ground at takeoff b. Listen to VOR voice channels c. Request with tone-data
Request Airway Use	Pilot activates 3 or 4 pushbuttons of the 100-dollar microphone input tone-data unit from his airway chart
Codes Available	3 tones - 4,096 4 tones - 65,536 VHF channels - about 40 Adequate codes in 1 to 2 second "burst"
Assessment of Interlock of Requested Airway	Listens to voice confirming request for 1 of possibly 100 airways within atotal of 6 to 8 seconds
Pilot Monitoring of Broadcast Control	Hears all other assignments to other pilots in his area as simplex VHF is used.
ATC Density	Low since all jets and high-performance aircraft use VORTAC R-NAV and radar/ computers, counters
Request Approach to Small Airport without Tower Personnel	Tone code noted on chart is used,and voice (canned) approval given by inter-locked system if airspace is free
Broadcast ATC Integration with NAS	Airspace assignments are in simple interlocked form available to a center if desired
Channels Used	VOR voice mostly and some "Unicom"
Waypoint Clearance	Pilot requests by tone data, receives a reply by "auto" voice and once executed, clears by tone data to the next waypoint

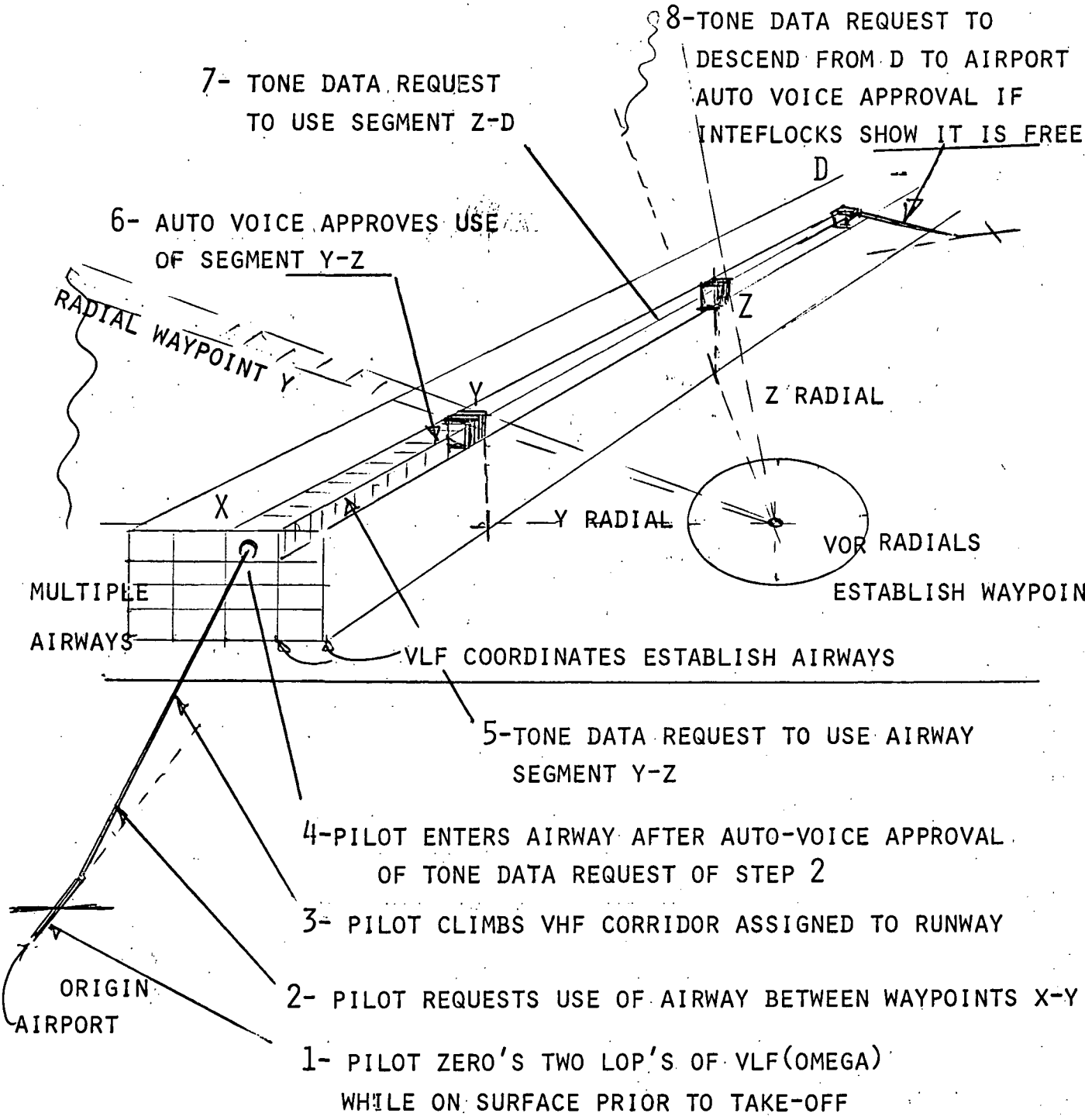
data tone buttons. Upon being accepted, he then utilizes the airway.

Thus, a pilot could takeoff, adjust his display to the first waypoint, and upon reaching it, push three buttons in rapid sequence (as in touch-tone dialling), taking about a second, and receive in the next few seconds voice permission to move from the current waypoint along the airway to the next waypoint. In coverage of a given VHF facility, many airways and many altitudes would be codified so that the tone-data would identify the desired airway segment automatically, and the "canned" voice reply would confirm commitment and assignment.

The pilot could then continue through a series of waypoints, being assured of his single airway occupancy between specific waypoints by the above low-cost tone-data means. He arrives at his destination normally without any direct human controller monitoring or any radar-vectoring. Figure 10 illustrates these basic Broadcast Control principles.

In dense terminal areas the controllers will organize priorities since the complexities of feeding, say, parallel runways from 6 airway directions and 10 latitudes creates some 120 possibilities. Contrary to this, in a general aviation airport with a single runway and low-density, dispersed air traffic, no such controller intervention is needed. This use of enormous amounts of new airspace that become available with VLF airways lowers density of traffic enormously, adds capacity, and thus allows these greatly simplified concepts of Broadcast Control to be realized. The ground communications complexity is very low, using production units of the Bell system tone-data decoders, interlocks, and canned messages.

NOT TO SCALE



BROADCAST CONTROL USE OF VLF/VOR AIRWAYS BY LIGHT GENERAL AVIATION AIRCRAFT POPULATION

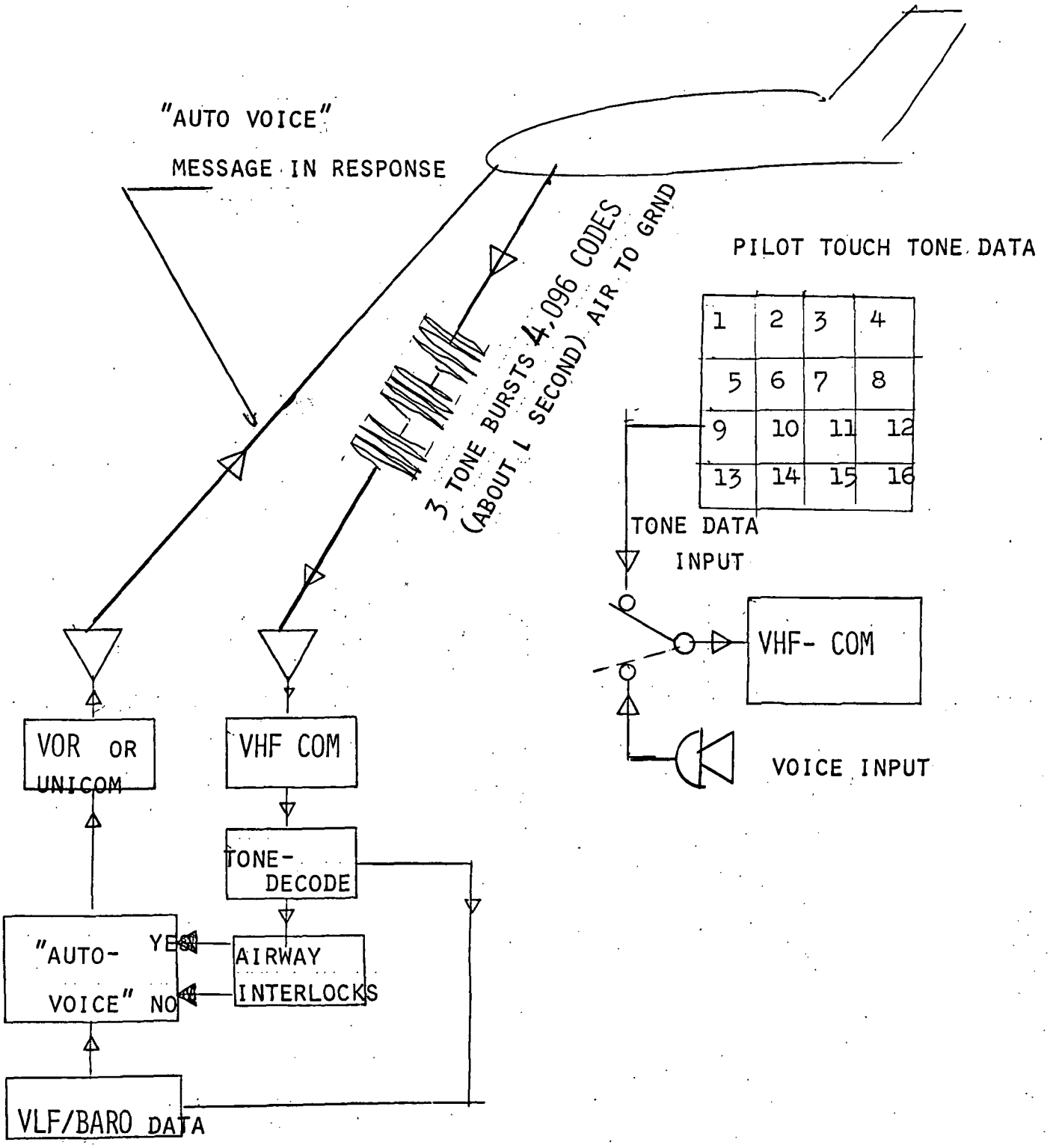
FIG 10

DIURNAL VLF DATA FROM COMMUNICATIONS

Diurnal changes must be inserted occasionally in the VLF use of airways structures, just like one has to insert new bearings and select new frequencies in VOR. However, the communication job of assuring all pilots at all times of the local diurnal setting (for differential Omega) is essential to this new concept of Broadcast Control based on "wide-area" navigation. Here the marriage of VOR and Omega is obvious. The pilot can set his runway position in VLF coordinates very easily at takeoff, essentially making the first diurnal correction. When he then requests an airway segment, this can be solicited from a VOR station.

In addition to replying to this specific aircraft (and locking out the airway to other requests), the VOR automated voice response can also communicate to the pilot by "canned" voice the exact diurnal setting in that area. Since VHF signals travel only for a given (line-of-sight) distance, this will confine this data to an area possibly about 50 miles surrounding that VOR station, so that a diurnal correction of the same VLF coordinates in California is not confused with the diurnal corrections in New York, even though both aircraft are receiving the same VLF radio navigation transmissions. Even though 3,000 miles apart (one of the enormous virtues of VLF), each aircraft receives from the VHF Unicom or VOR the correction specified only for that area. Figure 11 suggests the elements in this air-ground-air communications function used in Broadcast Control.

Next, communications should also supply a recent barometric altimeter setting, as the use of all airways are so dependent on vertical separation data. It is obvious that data for baro-settings



AIR-GROUND AND GROUND-AIR COMMUNICATION LINK

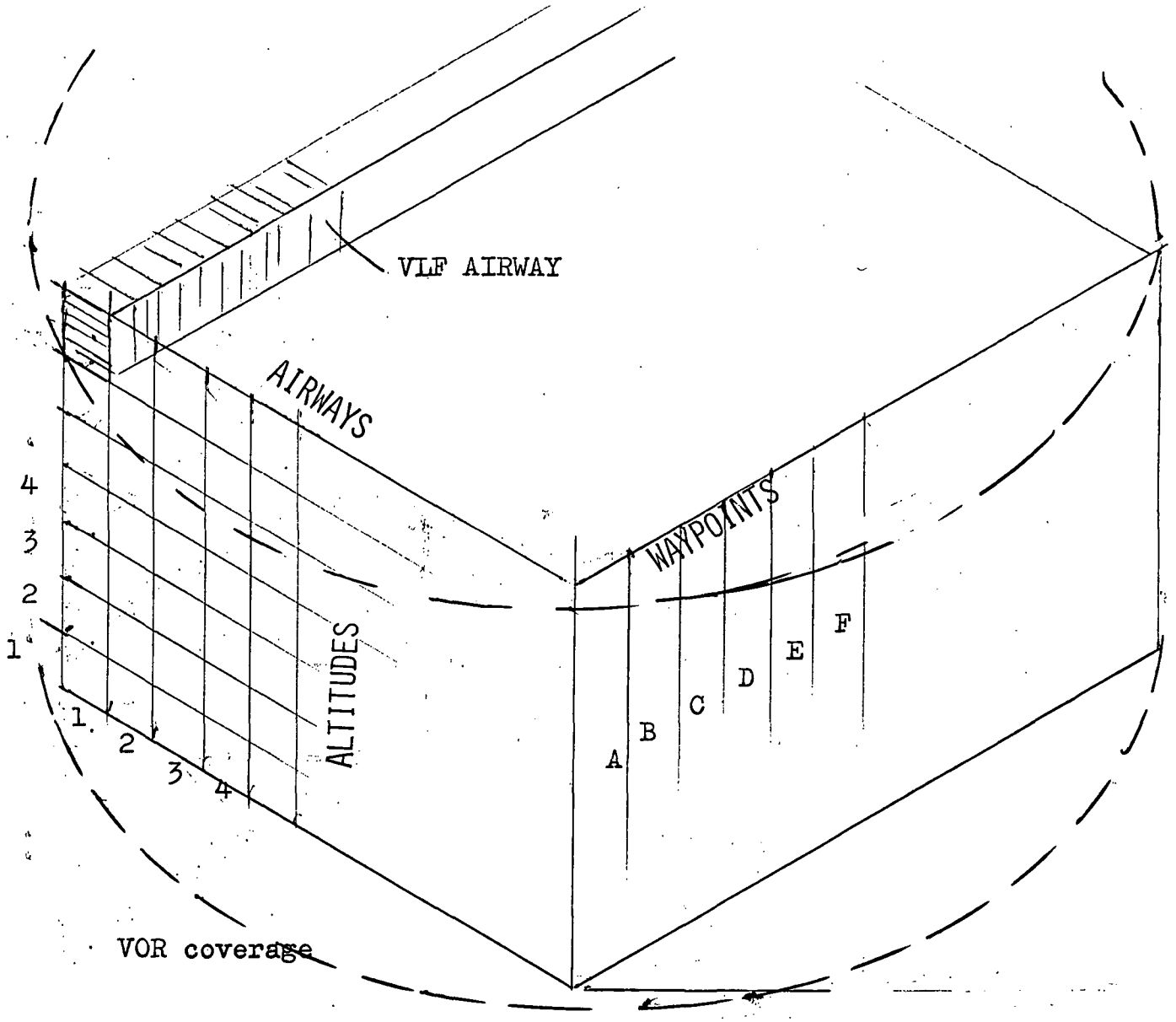
FOR BROADCAST CONTROL OF ABOUT 85% OF GENERAL AVIATION

FIG 11

and diurnal settings can be sent on the VOR voice channel at a much lower rate than the ATC Broadcast Control data that requires some form of closed-loop acknowledgment to the pilot. By avoiding ground-vectoring and using VORMEGA R-NAV, the ground to air communications load is very low. In Broadcast Control mostly "go-no-go" answers are needed to tone data requests for 3-dimensional airspace. Since so many additional flexible airways will be created with VORMEGA, nearly all replies will be "go."

If, for example, airways are every 5 miles based on (1) VLF coverage and (2) general aviation use of 10 altitudes, then within the VHF COM coverage might be 100 airways that can be numbered 1 to 100. Next, we might have waypoints on each airway every 10 to 20 miles assigned the letters "A" through "K", as in Figure 12. In this manner, a maximum of 1,000 codes of the 4,096 codes available (3 bursts of the 4 X 4 dual-tone system) are utilized. Possible use of the remaining 3,000 codes would allow expansion of waypoints, ATC requests, approach tracks, etc. Since all VOR channels must be "clear," this would mean that the adjacent VOR stations would each provide another 1,000-segment capacity, or we can now use this for control of airspace separated from the first VOR. Thus, RF channels could further increase this potential communications capacity (nationally) by about another 40 times.

Since it takes a general aviation aircraft following these airways about 4 to 5 minutes to fly 10 miles to the next nearest waypoint (see Figure 12), we must consider that the most frequent communication cycle for a given aircraft. The air-to-ground tone-data solicitation and the ground-to-air (automatic) "canned"



ASSUMING 10 ALTITUDES AND 10 PARALLEL VLF AIRWAYS WE HAVE A TOTAL OF 100 AIRWAYS IN AN AREA ABOUT 100 X 100 MILES WITH 10 WAYPOINTS ON EACH AIRWAY WE HAVE A TOTAL OF 1,000 DISCRETE AIRWAY SEGMENTS THAT CAN BE ALLOCATED IN BROADCAST CONTROL USING 3 BURSTS OF BTL TONE DATA FROM THE AIRCRAFT TO REQUEST THE DESIRED AIRWAY SEGMENT (TIME REQUIRED 1 SECOND)

FIG 12

voice (confirmed) reply takes about 6 to 7 seconds, then an aircraft's maximum utilization (reporting and requesting at every waypoint) of the channel would be about 2 to 3 percent of the time, thus allowing other aircraft to use it 97 to 98 percent of the time.

Since it is likely the pilot will usually ask for a long segment (say 20 to 50 miles), and it can be approved because of our very large airway capacity and the dispersion of traffic, then this reduces the communications load considerably, possibly making it suitable for serving about 30 to 50 aircraft per VOR voice channel. It is also possible to assign a "Unicom" channel to this Broadcast Control service if the traffic warrants it.

However, if, say, in a 100 X 100 mile area one finds typically 10 to 15 VOR stations, the Broadcast Control communications capability would be (for this 100 X 100 mile area) as high as 300 to 400 general aviation aircraft all simultaneously using Broadcast Control. This is one of the major merits of Broadcast Control in Area-Nav--a large reduction in air-ground communications. All "VFR" flying would utilize this Broadcast Control concept, since the concept in essence gives freedom of movement, It also supplies to all users (by listening to communication assignments) identified airspace occupancy data, so that most of the many "VFR" mid-air collisions can be avoided.

The very fact VLF is used to generate hundreds of new airways for general aviation with routings to thousands of outlying airports will assure the authorities that a specific aircraft is not violating the airspace of others. This violation often occurs

in VFR rules by error on the pilot's part--either not knowing where he is, not knowing the 3-dimensional limits of high-density airspace, or simply attempting VFR flight under questionable visibility.

BROADCAST CONTROL COMMUNICATIONS COSTS MUST BE LOW

Thus, it is evident that in addition to the VORMEGA navigational coordinates that are a basic part of the Broadcast Control of air traffic, a communications link must also be designed for Broadcast Control needs. Fortunately, these needs are much less than high-density Close Control concepts, allowing low-cost innovative techniques. The total costs for Broadcast Control to appeal to general aviation must be considerably below current costs of VORTAC R-NAV equipments and data-links, such as "DABS." Assuming VHF-COM is very widely used, the total added communications costs for Broadcast Control should be about 100 dollars by adding the 4 X 4 pushbutton tone-data board (one of 16 tones for each activation of a button representing a digit). This is small, light, transistorized, and can be added to any cockpit. The microphone input takes the data tones since they are all inside the band pass of voice frequencies*. The exact tones received extensive tests and were selected for this bandwidth and to be immune from voice jamming (see references 5 and 6).

LONGITUDINAL SEPARATION IN BROADCAST CONTROL

The means for providing many new airways with the VLF coordinates has been discussed. These are effectively new airways

* Typically they are frequencies of (Hz) 697, 770, 852, 941, 1209, 1336, 1477, 1633.

TABLE IV

SUGGESTED USES FOR BELL SYSTEM'S "4 X 4"
DUAL-TONE DATA FOR AIR-TO-GROUND COMMUNICATIONS

1. Investigate it as a major element in Broadcast Control concepts to avoid ground personnel intervention.

2. Request airway use by tone code (up to about 160,000 codes).

3. Does not prevent voice use of VHF/COM, but speeds up transmission and data handling in Broadcast Control.

4. Reception on the ground is automatic and can key automatic voice response for specified airway approval, etc.

5. Retains voice as ATC reply on ground-to-air link voiding need for costly airborne decoding equipments ("coding" is usually low in cost, and "decoding" is usually high in cost).

6. Pilot requests airport lights to be turned on.

7. Pilot can request automated barometric data.

8. Pilot requests approach to unattended airport (no tower) via FSS and ground interlocks.

9. Can "encode" manually or automatically any air borne data for air-to-ground transmission such as identity, position, altitude, etc.

10. Pilot requests clearance on airway to given waypoint with approval via voice response from ground unit, without controller interventions in low-density ATC areas.

11. A low-cost means of bringing Broadcast Control and hundreds of new airways to general aviation's lowest price range.

12. Provide waypoint-to-waypoint clearances on specified airways.

13. Air-to-air position reports monitored by pilots listening to a common voice channel.

14. Emergency codes, many other possibilities of unique messages.

15. Semi-automated request for VHF bearing data (VHF/ADF).

16. Low-cost, semi-automated tower functions at non-personnel towers.

17. Can add minimum "discipline" needed for Broadcast Control of about 80 percent of general aviation aircraft and approach discipline to about 10,000 airports used by general aviation without towers.

making use of airspace for air traffic control purposes that would otherwise be unavailable. The contiguous nature of the VLF coordinates, their uniformity and universality of coverage avoids large gaps in coverage and geometric convergence typical of VOR and VORTAC that denies much airspace. The marriage of VOR and Omega is herein proposed because of the great number of advantages, particularly to general aviation users of the national airspace and, therefore, the urgent need for extremely low-cost "area-navigation" and low-cost Broadcast Control.

Thus, the pilot can request with a 3 to 4 tone-data "burst" taking about a second the availability of one of possibly 1,000 airway segments or combinations of segments defined in three dimensions. Waypoints on the airways can be assigned by traffic density to reduce communications and pilot workload. For example, an airway might have 3 waypoints; if it is in use, possibly only the airway to the first waypoint is assigned. If the airway is unused, all the waypoints (a series of airway segments) can be assigned by simply blocking out that airway for a time and satisfying the next request for it with one of the immediately adjacent airways. In low-density traffic typical of airspace removed from jetports and jet airways, this implies nearly every flight has a "private" airway since VORMEGA will have such enormous airway capacity as compared to today's airway capacity. However, the question arises of how spacing along the assigned airway is maintained in this concept of Broadcast Control.

As is done today, all pilots listen to all air-to-ground and ground-to-air voice communications on the VHF channels they

are assigned for ATC. This gives each pilot a mental picture of the traffic about him and what the intent of the traffic is. Enormous intelligence concerning adjacent aircraft, ATC plans, flow rates, errors, emergencies, etc., can all be gained by simply listening to the air-ground voice data used in ATC.

In monitoring air-ground VHF communications, it is evident that the pilots are excellent judges of the actions of controllers and pilots of other aircraft. A controller must be concerned with perhaps 6 to 10 aircraft under his responsibility; while the pilot is concerned with but his own aircraft's safety, expedition and well being, as it is the only one he controls. The pilot views the ATC process from his coordinates in the system (say, an airway, altitude and fix), catching any errors controllers or other pilots make in altitude assignments, estimated times to clear fixes, etc.

Retention of voice in any ATC process is essential to permit even the minimum involvement of the pilot. Otherwise, he must take with blind faith instructions good or bad from the ground. Shortly this can be worse with automation of SSR data and DABS, both of which tend to further remove the pilot from this essential involvement he now has with voice data experience.

In Broadcast Control using Area-Nav, we hope to reverse this trend bringing the pilot more into the ATC loop, creating major economic savings, greater efficiency, and safety in the ATC process. Thus, rather than deny the pilot and/ reduce the importance of voice data, we would increase the emphasis on / voice data in Broadcast Control as being the most versatile, low-cost, ground-to-air data transfer system that exists. Voice does not need additional data-link receivers, annunciator displays of "commands", etc., for realizing the benefits of Broad-

cast Control. This is primarily because Broadcast Control, although using voice data, uses much less ground-to-air communications, while Close Control, as in DABS, uses more and more, saturating voice capabilities and forcing new capacity by digital data links that cannot be "listened" to by others or cannot be interpreted directly without a costly decoder. In a few words, this is the dilemma in ATC that faces us in the 1970's and 1980's.

The pilot in the Broadcast Control concept, of course, hears the voice assignments from the ground, so that if he is located in a given airway, he would hear the assignment of adjacent airspace above, below, ahead, and behind him. Assignments to a given aircraft provide both its location and identity by voice. For example, the auto voice would say, "Aircraft XYZ is assigned airway 77 to waypoint L." Since this is heard on the one VHF channel assigned to that airway and adjacent airways (such as a Unicom or the VOR voice channel), an added step in the selection process takes place. Another pilot, who may be between fixes M and N on airway 77, hears the assignment to waypoint L and now knows that another aircraft is on his airway but separated from him by the distance between the two fixes, L and M. Unidirectional airway travel prevails as in the current "rules of the air," that have been established for many years.

Thus, to repeat, it is possible for the pilot (by voice monitoring) to create a mental picture of the airspace assignments and occupancy by other aircraft since uniformity of airways is already possible with VLF transmission. As he or the other pilot subsequently arrive at their waypoints and request clearance through them, the two pilots can monitor this fact. It is also possible in the

Broadcast Control technique to add some form of air-to-air "proximity control" as a reassurance that the supposedly adequate separation, using waypoints, is being maintained. One such system is to make use of the ATC transponders that are becoming nearly universal in their airborne applications. The aircraft transponder "listens" to the pulse replies of the aircraft near him, and by a filtering process of common-azimuth, common-time-differences and co-altitude decoding of the beacon pulse coded replies, it is possible to obtain an air-to-air measurement to aid in "proximity control" (see reference 7).

Thus, the pilot would obtain from his (1) monitoring of the voice ATC data that assigns the airways and waypoints and (2) if available in SSR coverage, an independent measure of the proximity of other aircraft at his altitude, assurance that Broadcast Control was working properly. If the pilot is aware from voice data that the next block of his (airway) airspace is occupied, this will alert him to keeping closer watch on his proximity control indicator. Even though blocks for general aviation use would be a minimum of about 10 miles and usually longer (say, up to 50 miles long depending on ATC needs in a given locality), it would be reassuring to the pilots using Broadcast Control with little ground personnel intervention that another aircraft for some reason is not too near the block limits or has somehow made a cockpit error--something all systems are susceptible to, and must therefore have some form of redundancy.

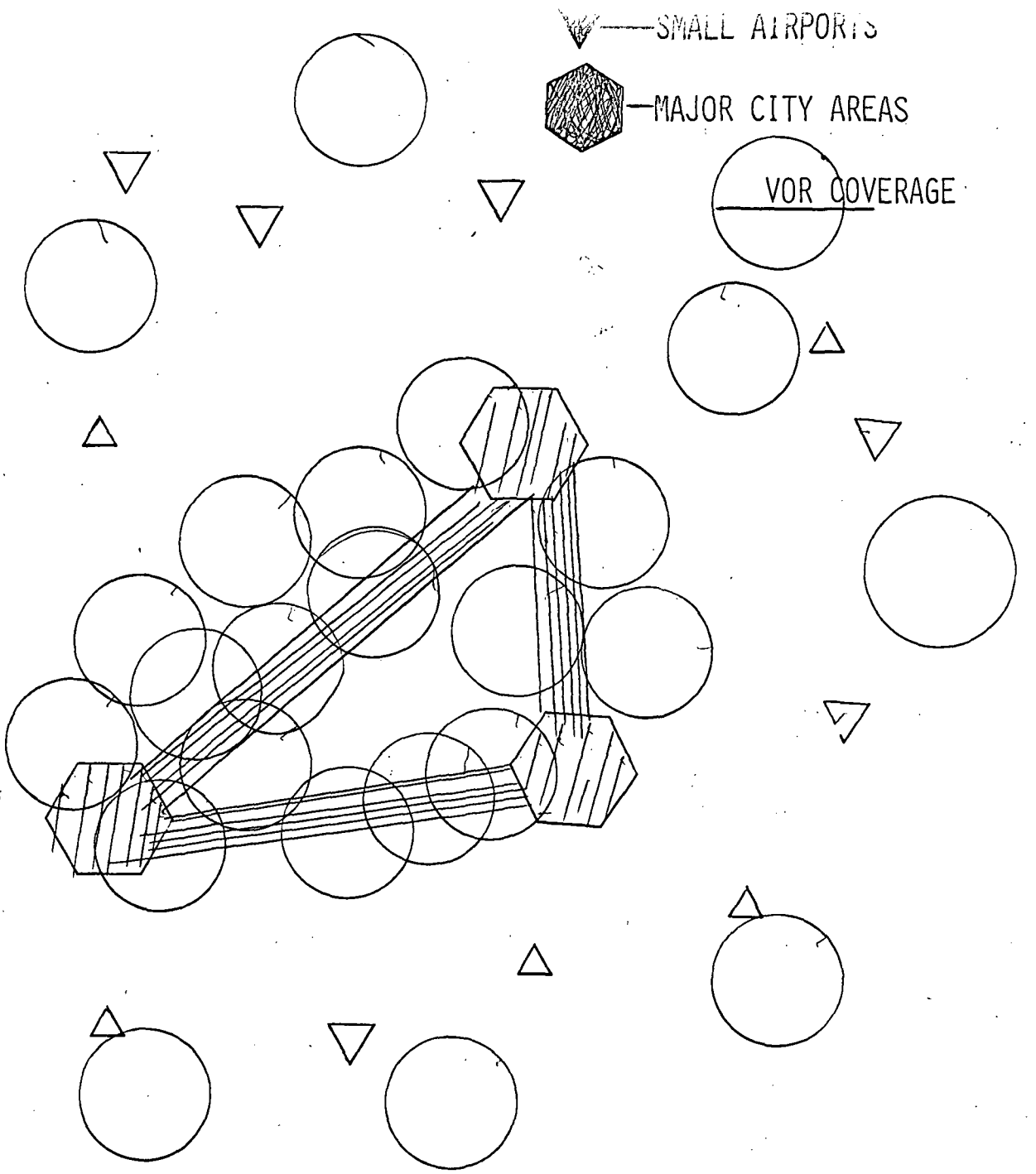
MONITORING OF BROADCAST CONTROLLED AIR TRAFFIC

In low traffic density areas where towers are not available and ATC centers do not serve, we can offer to the tens of thousands of general aviation aircraft an ATC service that fits their needs economically, technically, operationally, and is consistent with regulatory practices. The present deficiencies: (1) wasteful use of airspace by VOR airways which also caused (2) local congestion when aircraft use what airspace is adequately defined by VOR are both overcome by a "total coverage" system of VLF/VOR, such as VORMEGA.

The known weaknesses of VLF-Omega can be overcome either by integeating the Broadcast Control concepts with VOR (in a VORMEGA), or ultimately using a new VLF system, custom engineered, tested and installed solely for the contiguous geographic area of the United States. Such a plan allows back-ups by separate use of VOR in case of Omega failure, and use of Omega where VOR has failed or is deficient, such as at low altitudes, on the airport surface, mountainous regions, and at hundreds of remote airports.

Rather than adding a burden on the SSR monitoring at towers and centers of traffic utilizing Broadcast Control, we will use self-monitoring and self-discipline techniques by the users. This new ATC capacity will at least double the potential airways, giving more than enough defined airspace to general aviation and, most importantly, arranging the airways to go to thousands of small airports rather than to the centralized jetports and cities where the VORTAC station coverage is most dense (see Figure 13).

We will use a very low cost air-to-ground VHF tone data



- VOR STATIONS ARE LOCATED NEAR LARGE CITIES AND ALONG ROUTES CONNECTING LARGE CITIES.
- VOR STATIONS ARE POORLY LOCATED FOR OUTLYING GENERAL AVIATION AIRPORTS.

VOR STATIONS SERVE MOSTLY DENSE TRAFFIC

FIG 13

TABLE V

ATC FACTOR	VORTAC R-NAV	VOR/OMEGA R-NAV
Type user	Fast, high-flying airliners and jets (about ten thousand)	Slow, low-flying, 85 percent of general aviation aircraft, or about 150,000 aircraft
Inputs to the ATC process	VOR; DME; 3-dimensional barometric altimeter. Creates airways on new display that are horizontal, vertical, or both	VOR receiver now in most general aviation aircraft; add only an Omega receiver and an R-L indicator for airway performance
Location of R-NAV airways	Between jetports	Parallel to VORTAC airways and below them and leading to 10,000 general aviation airports
Costs	Very high, but commensurate with airline use and jet aircraft costs; minimum cost estimated by some at $15,000	Within reach of possibly 80 percent of general aviation aircraft that cannot afford VORTAC R-NAV (add about 1 to 2 thousand dollars
Type of control	"Close Control" such as radar-vectoring or DABS, requiring computers and many ground personnel	"Broadcast Control" with major pilot participation and few ground personnel
Use of airspace	Adds somewhat to the capacity of the VOR airways but serves same high-density areas as now	Creates possibly 2 to 3 times (new) amounts of non-conflicting airways, mostly suited to general aviation and STOL vehicles in low-density areas
Back-ups	Dual VOR and DME needed as DME is not an LOP system. SSR transponder and radar vectoring also available	VOR backs up Omega; Omega backs up VOR, as both are lateral LOP systems, using simple coordinates
Three-dimensional requirements	Spherical coordinates with randomly located sources must be tied together and corrected in three dimensions	VLF and VOR are "planar" LOP coordinates when used in Broadcast Control avoiding three-dimensional corrections

Preliminary Draft

link to request use of this new airspace (not the VORTAC Area-Nav airspace which is reserved for jets primarily). This "segregates" the air traffic geographically and vertically in accordance with ability to pay, speed, climb-descend needs, cruise altitudes, origins-destinations, and importance of the missions. This newly segregated system would utilize Broadcast Control methods for establishing and authorizing flights along the vast new airways structure created by the combining of VOR/Omega concepts. The costs are so low as to be acceptable to the lowest economic layer of general aviation (the nearly 200,000 single-engine aircraft expected in 1980-1990, for example). We will rely on Omega as a back-up for VOR where its signals are off the air or limited by propagation, and use VOR as a back-up for Omega in case of signal disturbances; so that when the two independent LOP systems are used for Broadcast Control, "escape" tracks exist. Either holding a few minutes for the signal to return or flying to a safe destination areoptions open to the pilot in this concept. One cannot do this with VORTAC as DME is not a linear LOP, but a circle; it is also an LOP that is uninstrumented for track following and thus cannot be used for these and other limitations as a back-up for VOR failures. Consequently, as VORTAC R-NAV progresses, the costs for even "basics" will be doubled for this type of service since dual VOR and dual DME will be essential to creating and Area-Nav LOP with some form of a back-up. Omega can create its own multiple LOP's once diurnal corrections are applied.

Thus, not only is the pilot assured of the reliability of airway coordinates in Broadcast Control, but he can follow them by cockpit requests using his tone data input unit. He then listens

to the VHF channel to receive his own approvals (addressed to him by time correlation or actual identity). Just as important, he also hears the other assignments to other pilots, so that if any conflicts occur, the pilots can then use direct air-to-air voice to resolve the conflict without intervention of ATC personnel from the ground.

This concept of VFR and IFR airways is appealing to low-density ATC areas, where radar centers or towers are not likely to be available, Even though VHF and SSR signals exist in the airspace, the authorized airways are but a small part of this propagationally covered area because of the serious "geometric" constraints noted previously. Propagational coverage of an area or volume with radio signals and authorized airways is an entirely separate matter. One is engineering; the other is operational. Station location or its limited coordinates and LOP's often deny much use of the airspace with airways, even though it is actually covered with radio signals. All airways converging to a single point create high-density traffic only at one point, while most other points are not served at all, with nearly zero traffic.

Broadcast Control tends to add the type of discipline that pilots can cope with and removes much of the current fear of "VFR" flight where uncontrolled traffic can mix with controlled traffic--or even worse, in VFR conditions of 3 to 4 miles of visibility when it has been shown to be almost impossible to visually detect a potential collision in time to avoid it. So-called "controlled VFR" flight or "VFR Airways" assures all parties, controlled and uncontrolled, that a national standard on discipline

and the use of airspace exists in Broadcast Control systems.

Airspace can be available by a simple, inflight, cockpit request; however, once assigned it is known to others. Of course, the general aviation Broadcast Control traffic data flowing to and from the ground (with little controller intervention) is also fed by telephone lines to a centralized point, such as a center or Flight Service Station if it is desired for processing purposes or monitoring. However, this is for monitoring, not for control functions. It is also useful for recording traffic statistics or for emergency search and rescue functions if any aircraft is lost. This monitoring in Broadcast Control concepts is quite a different concept than radar-vectoring, where so much manpower and costly/complex high loads on communications (and potentially unreliable) ground equipments are involved, as in Close Control techniques.

SUGGESTED R AND D PROGRAM

It is suggested that some of the available low-cost Omega receivers now becoming available be used for some operational flight testing of the many concepts and procedures that constitute a Broadcast Control ATC system for general aviation. These include:

1. Test the concept of a 400-foot/1-NM, non-precision approach to every runway in the nation.
2. Determine difficulty of always having the VLF navigational LOP aligned with the extended runway centerline for approach to avoid "circling."
3. Determine from flight testing the use of "crossing-LOP's" from these inherently available in the Omega system, and if a

suitable "distance to threshold" (DME) is available as well as the extended runway centerline non-precision approach guidance tested in (2).

4. Tests of the pilot's use of simple barometric data and the VLF data to "construct" a non-precision vertical path to the runway centerline. Flight test available instrumentation that has been modified for this purpose.
5. Acquire and test the tone data-link of BTL with a 4,096 code structure at first to determine if pilot ATC solicitation "burst" can be completed in one second of time and its reliability.
6. Acquire BTL tone data decoder and connect to the output of a VHF-COM (Unicom) ground receiver to determine reliability of VHF decoding and ability to reject voice interference of codes on the same channel.
7. Confer with Bell Labs staff on their extensive "voice-immunity" tests.
8. Test "auto-voice" available from Bell Systems that will provide a voice reply to the pilot's solicitation utilizing coded inputs for airway requests, diurnal check, baro-data, automated-tower clearances, and ability to relate interlocked conditions of airway assignments essential to Broadcast-ATC concepts.
9. Configure a basic Broadcast Control system consisting of pilot tone data solicitation, ground reception of tone data, decoding and assignment of specified segment of a specified airway without human intervention on the ground.

TABLE VI

SUMMARY OF PRINCIPLE FEATURES OF BROADCAST CONTROL OF GENERAL AVIATION AIR TRAFFIC BASED ON THE USE OF VORMEGA AND VHF-COM

1. Thousands of new VLF airways and approaches to small airports can be authorized with waypoints defined by both VLF and VOR radial crossings of the airway.

2. This provides enormous new airway capacity, particularly as low-density airways well suited to the widely dispersed general aviation airports.

3. Each flight can now be assured of optimized routing from this new capacity of airways, and assignment of a long airway segment; greatly reducing air-to-ground and ground-to-air communications. Pilot workload is lower.

4. The pilot uses tones in the voice band as inputs to his comm transmitter to request from a 4,000-code selection a given airway segment in three dimensions and receives adknowledgments from ground-based tone decoders, interlocks and auto-voice.

5. Human voice is the ground-to-air data transmission system. Mostly Bell tone data system is used in the air-to-ground link with voice also being available. Tone data is immune to voice interference.

6. Pilot proceeds to use airspace he desires. If occasionally his first choice is already occupied, an adjacent lane airway can be approved from the large airway capacity.

7. Pilot execution of airway following (Area-Nav) suited to any geometric shape (direction, segmented, etc.) greatly reduces communications load. No radar surveillance is needed since ground interlocks prevent assignment of same airways segment to two aircraft at the same time.

8. Pilot may proceed without intervention of ground (ATC personnel) using the "closed-loop" of Broadcast Control via the tone-data solicitation and auto-voice reply from the ground interlock system that can be a part of the flight service station concept.

9. Assuming airlines use VORTAC R-NAV on dense air routes between major city pairs, Broadcast Control assures all pilots that general aviation and airline traffic remain separated and controlled under all conditions.

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