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FLIGHT STRIPS

DESIGN AND CONSTRUCTION

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FLIGHT STRIPS

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A flight strip as originally conceived and planned by Lieut. Col. Stedman Shumway Hanks is a flat area of land not less than 200 feet in width or less than 1,800 feet in length with clear approaches located adjacent to a public highway but is a part of the highway right-of-way itself. Under the definition, a flight strip automatically becomes the responsibility of the various state highway departments; any state laws relative to flight strips should be conceived as part of the existing highway and motor vehicle laws.

As proposed, flight strips would be acquired by eminent domain, in the same way land is acquired for highways. They would be developed with Federal funds appropriated to the state highway departments in accordance with defense highway act of 1941 supplement (S-1840). See appendix.

Strip landing fields, as the name implies are landing areas of such dimensions that landings are possible only along the line of the longitudinal axis. Since they permit landings in only two directions, they are not suitable for use as general aviation bases but they are of value for military, civilian and emergency use.

The object of providing a system of flight strips throughout the country is to make available great numbers of small conveniently located landing areas which could be used as an auxiliary landing area near an airport, as an emergency landing area between airports, as an auxiliary field for the G.H.Q. Airforce of the United States Army Corps in an emergency, or as an aid to the private flyer.

It is estimated that 400 auxiliary landing areas or flight strips would be required in continental U.S. exclusive of existing landing fields. This, of course, depends on the size of the air force.

This discussion of the "Design and Construction of Flight Strips" is to provide persons charged with the responsibility for the planning, design, and construction of flight strips with the basic information to assist them in understanding the broad general principles involved and in working out the details of a sound program of flight strip development.

The scope of this discussion is limited to the presentation of the basic considerations in the planning and selection of flight strip sites. Their design, construction and maintenance and including such special considerations as camouflaging, necessary utilities, lighting and aeronautical details.

PART II

PLANNING AND SELECTION OF SITE

Much has been learned in the past few years concerning the necessity of proper planning in the construction of airports, and the information now available, if utilized is sufficiently comprehensive to insure satisfactory results in the construction of flight strips. It is a well known fact that a comprehensive, preconceived plan is of essential importance if costly mistakes are to be avoided.

A study of stratigical or tactical locations would first have to be made. There would be no buildings on the flight strips, and the only men required would be maintenance men required to maintain highways normally. Ability to cut in on phone lines would be helpful.

In level country, flight strips need not be adjoining the road but might better be parallel to it, and separated from it; however, in certain hilly parts of the country areas, adjoining the road might be the only level areas available.

In the matter of selection of site the commissioner of Public Roads will direct his district Engineers who in turn will deal with the state highway commissioners. The War Department does approve the acquisition of all sites which are applicable for the particular purposes for which they will be needed.

The many factors which appear in planning and selection of flight strip sites will be discussed under the five subjects, economic considerations, aeronautical considerations, physical factors, military and civilian considerations.

Economic Consideration

In the planning of flight strips the type of air service which the strip will receive must be given consideration. Since a flight strip is intended to serve as an auxiliary landing field for both military and civilian planes, the size, weight and flight characteristics of the various planes must be considered. The original definition of flight strips by Lieut. Col. S.S. Hanks definitely establishes the flight strip in a position whereby they must be capable of serving the largest army planes of 50,000 pound weight and over in emergencies as well as the smallest civilian private plane.

Future Expansion: In certain locations it may be desirable to consider the possibility of expanding a flight strip to improve its efficiency as an auxiliary or emergency landing field for a local airport. The economic factor relative to future expansion must be considered.

Accessibility and Relation to Existing Transportation Facilities: Of special importance in the selection of flight strip sites is their coordination with various forms of surface transportation. It is essential that they have direct connections to adjacent highways.

Future Recreational Facility: It is anticipated that the future holds a great expansion in aerial tourist travel, including private planes, and charter operations, to local and remote recreational areas. Flight strips should be planned so that centers of population and recreation may benefit.

Cost of Right-of-Way: The flight strip as originally conceived is an area of land adjacent to a highway. The acquisition and improving of this land should be consistent with the value of the development projected.

Cost of Construction: In the selection of a flight strip site the various factors incidental to construction should be carefully considered.

Physical factors such as topography, soil conditions, availability of construction materials, natural drainage and native shelter at the site may well influence the decision in favor of this site over one not so favored, all other factors being equal. It is estimated that the normal cost of constructing flight strips will average $50,000 to $100,000 apiece.

Aeronautical Considerations

Each location with its particular local conditions presents a different problem when the selection of landing site is considered. Primary consideration should be given to those aeronautical factors which directly affect the safety of aircraft operations from a flight strip. These factors may be summarized briefly as, an adequate area, freedom from surrounding obstructions, its relation to existent airways, proximity to other landing fields or airports, favorable meteorological conditions, conditions which affect visibility and zoning requirements.

Flight Strip Area: The amount of land necessary for flight strip areas has been established approximately by specifications set forth in the Defense Highway Act of 1941. An area should be not less than 300 feet in width and not less than 3,000 feet in length and may be 800 by 8,000 feet where terrain will permit and depending on the type of military airplane using the area. The runways should be not less than 3,000 feet in length for the use of pursuit aircraft and not less than 4,000 feet in length for the use of all other military aircraft. Runways which do not cover the entire overall width of the flight strip areas should be not less than 150 feet in width for military aircraft. The above lengths are at sea level and therefore subject to corrections for elevations. The above width of 150 feet is intended for the landing of one plane at a time.

Another important factor influencing the size of airports and the necessary length of the runways is the elevation of the airport above sea level. Increased area must be provided at higher altitudes for the take-off run and the landing run, as airplanes land and take off at higher speeds and climb at flatter angles as the altitude above sea level increases. This is due to the normal decrease in atmospheric density and the consequent decrease in the lifting effect of the air on the wings, and in certain types of motors, resulting in a decrease in the amount of horsepower delivered. See Table I

Freedom from Obstructions: Persons charged with the selection of an airport site should recognize immediately that structural or natural features surrounding a tract of land have a very material effect upon its usefulness as an airport and upon the size of the landing area required. At the time the site is being viewed, consideration must be given to the area adjacent to the field boundaries and particularly to the possible approach areas lying within 2 miles of the proposed site boundaries. Unsafe natural topography includes mountains, high hills, knolls, ridges and trees if they obstruct the approach zones to the runways. In most cases it is more feasible and less costly to select a site which is free of obstructions than to select one with obstructions which are costly or impossible to remove.

Before the final selection of any site where obstructions of a serious nature exist, such as power lines, high trees, stacks, etc., the practicability of removing or reducing all obstructions to a safe permissible height should be assured.

Location with Respect to Existent Airways: When there is an established lane of air traffic in the vicinity, preference should be given to a site which is located closest to the existing airway. Flight strip area located near existing air lanes would be readily accessible for civilian use and emergency landings for all types of aircraft.

Location with Respect to Other Landing Areas: The location of flight strip areas with respect to Army air bases or airports should be from 5 to 50 miles.

Meteorological Conditions: Proposed sites must be carefully investigated as to wind, fog, and smoke affecting general visibility in the vicinity. Prevalence of ground fog due to adjacent swamp land or bodies of water, adverse wind currents and directions as influenced by earth configuration, direction of wind blown industrial smoke and fumes as they affect visibility in the vicinity of the airport site must be considered. A study also should be made of wind direction and duration at the proposed site, as the direction of prevailing winds influences the layout and alignment of the runways and also the location and layout of the building area.

Location with Respect to Utility Services: Although subsidiary to a number of the factors already listed, some consideration should be given to the distance which electric power, telephone, gas, water, sewer lines, etc., must be extended to serve the proposed site, and some estimate should be made of the cost.

Zoning: The zoning of flight strip marginal areas to prevent the erection of structures and objects hazardous to flight operations in the neighborhood and to remove and regulate existing obstructions is very important.

Airport zoning is today accomplished by varying city, county, and state ordinances and statutes. The existing ordinances and statutes should be made to apply to flight strips.

Physical Factors

The major physical factors to be considered in the selection of any flight strip site are topography, soil conditions, availability of local materials, natural drainage and natural shelter as related to camouflage operations.

Topography: The configuration of the terrain on the adjacent to any proposed site should have careful consideration. First, comes the securing of sufficient usable area within the limits of the land to be purchased. Since the cost of grading, draining, surfacing, etc. may be materially affected by the topography of the land under consideration, the area should lend itself readily to development at reasonable cost.

The selection of a suitable site requires a balance between two opposing factors. The first is the necessity for obtaining a plot of ground which departs sufficiently from the dead level condition to provide adequate natural drainage, and the second is the necessity for obtaining a site which will not require heavy grading, yet will not contain slopes so steep that serious erosion may result.

Sites which lie in river valley land should be thoroughly investigated to determine the frequency and extent to which the site is subject to valley floods.

Sites of a natural bowl formation having low centers and relatively high borders and sites which are located on knolls and which lend themselves readily to grading in such a way that they will slope gently in several directions, or those which are on one or more planes so tipped as to drain freely to the sides or to internal valleys, offer especial advantages in that the terrain may be economically graded to permit the surface water to flow readily to points of collection in the storm water systems. Obviously any water that is removed quickly from the surface will not have the opportunity to soften the ground on its passage to the drains. A site whose topography will accomplish the rapid removal of surface water, will reduce greatly and, in some cases, eliminate the necessity of sub-surface drainage.

In some sections of the United States the local topography is rough, rugged and broken, and the construction of an all-way field would involve the excavation and moving of such excessive quantities of earthwork that the construction of this type of field would be economically unsound. In these sections, the landing strip type of field is more feasible, provided that adequate width and length is secured.

Soil Characteristics: An item which often receives too little consideration in selecting a site is the matter of soil characteristics. With this point in view, it is often possible to reduce materially the expenditure necessary for draining and surfacing. The most desirable types of soil for airport purposes are those containing a reasonable amount of porous material such as gravel, sand, or decomposed granite, combined of course, with a suitable natural binder. The undesirable types are the soils which become plastic and have a low-bearing power when wet.

It is essential that the flight strip be usable throughout the wet seasons of the year. If the soil on the site selected for the project does not possess sufficient self-draining characteristics to insure the safety of all-weather operation, artificial drainage and surfaced runways will be necessary to meet this requirement.

A soil survey is necessary to ascertain the performance characteristics of the soil at any specific site. The lack of proper regard for the importance of soil investigations and water table determinations may result in the selection of sites which will be very costly to develop.

Availability of Construction Materials: An item often overlooked in the selection of an airport site is the availability of construction material on or near the site. While it is true that the consideration is not basically a determining factor, nevertheless the fact that good gravel, sand or stone deposits are available at the site may well influence the decision in favor of this site over one not so favored, if the aeronautical features of the two are comparable.

A good gravel deposit, a potential rock quarry, or an acceptable grade of sand on the airport property is of great value since the material in question can be obtained at little cost and the haul is short. When sub-soil investigations are being made, it is of decided benefit to make a record of all borings and locate the extent of deposits of acceptable construction material, particularly if this material is located in areas which may not be needed for aeronautical use.

Natural Shelter and Camouflage: Camouflage principles should be considered in the selection of sites for flight strips. Such principles include the use of natural features and available plant material. It has been learned from England's experiences that to camouflage the fields is one of the most important developments in connection with landing areas.

Military Considerations

It is recognized by military authorities that flight strips are of vital importance to national defense. Therefore, flight strips should be designed to accommodate all types of military aircraft. They may be used for emergency stops or points for movement of air corps from east to the west or from north to south. Their proximity to aircraft industries may serve as a possible storage area for planes. Their location with respect to critical manufacturing areas should be considered for purposes of dispensing aircraft and operation for better protection against attack.

They should be accessible to local roads for bringing in gasoline supplies, oils and equipment, and for use as bivouac area for movement of troops, army tanks or mechanized forces.

Civilian Consideration

It is generally understood that flight strips would supplement airports by making available great numbers of small and conveniently located landing areas for the furtherance and convenience of aircraft. Therefore, in the selection of sites for flight strips consideration should be given to such factors that affect their utilization by private and commercial planes for emergency landing field and for private plane operation.

PART III

SURVEYS

The initial steps in the construction of flight strips is the execution of complete topographical and soil surveys.

Topographic Surveys

The topographic surveys are made in a manner convenient to the particular location, and in accordance with standard methods. The topography includes the shape of the ground and the accurate location of all objects that occur within the limits of the survey that will be of importance in the design of the flight strip.

The limits of the survey should include at least a mile from either end of the proposed runway and at least 1/2 mile on either side. The survey of such an area is necessary in order that complete information is obtained which might materially affect future development and operations of the flight strip.

The survey should include special attention to natural features, vegetation, tree growth plantings, crops and other items which might aid in camouflaging the area if the necessity arises.

The size and characteristics of the topographic map drawn from the survey notes will no doubt be a matter of individual judgement. A map scale of 200 feet to the inch with 1 foot contour intervals is recommended by the State Department of Aeronautics. They also recommend that the soil profile and soil classification be illustrated on the map as well as the location of the flight strip with respect to present airways and local airports. A typical map for a proposed airport layout will be found in the appendix.

The contours and the layout of the runway along with the elevation of the final surface, afford necessary data for general drainage system design.

Investigation of Soil Conditions

An investigation of soil conditions is an important part of the planning and the development of a flight strip site. The character of the soil profile, including such factors as ground water level and drainability, subgrade support for runways under all weather conditions, suitability of the soil for runway stabilization, and availability of construction materials will be a dominant factor not only in the first cost but also in the adequacy and permanence of the improvement.

A soil survey should be made on each flight strip site to obtain information as to local soil conditions. This soil survey should be made similar to the standard practice for highway construction. Although identification of soil types generally may be made by visual inspection, the field surveys should also be used to collect samples for the laboratory tests subsequently required for specific design problems.

Other purposes of the soil survey is to obtain information concerning the position of the water table, the presence of undesirable soil materials, character of material in cut areas, the location of suitable aggregate material for construction purposes and the availability of satisfactory borrow material if needed.

In some instances it may be advisable to examine the sub base soils for load bearing value and volume changes.

PART IV

DESIGN OF FLIGHT STRIPS

The best sites for flight strips are those that depart sufficiently from the dead level to provide adequate drainage without being too steep to result in erosion and those sites where runways of adequate length and width can be obtained without excessive grading. Sites of natural bowl formation, or those which are located on knolls where the land slopes gently in several directions, offers special advantages both for runway construction and for drainage.

The orientation of runways depends upon local conditions such as, variation in intensity and direction of prevailing winds, the height and position of existing the proposed buildings and other obstructions in the neighborhood of the flight strip.

The landing area is the foundation of the entire airport structure and its conditioning and development for all weather use are of prime importance. In general, the flight strip should provide a smooth, well drained landing area sufficiently firm to permit the safe operation of aircraft under all ordinary weather conditions, and should be approximately level and free from obstructions or depressions presenting hazards to aircraft operation.

The design of flight strips include such factors as dimensional layout, earthwork operations, drainage features, selection of proper surface and the consideration of certain camouflage principles for certain locations. These various factors will be discussed in the order mentioned.

Dimensional Layout

The Government's specification for flight strips for military purposes is presented as follows:

Over all size. -- An area not less than 300 feet in width and not less than 3,000 feet in length (the area may be 800 by 8,000 feet, where the terrain will permit and depending on the type of military airplane using the area), with clear approaches by air that will permit of the actual use of the full length of the runway.

Note: The term"runway" should not be incorrectly used for a "flight strip" because a landing area for aircraft is more than just the ground space required for the runway, apron and other facilities, if any. Runways which do not cover the entire over-all width of the flight strip areas should be not less than 150 feet in width for military use. The runways should be not less than 3,000 feet in length for the use of pursuit aircraft and not less than 4,000 feet in length for the use of all other military aircraft. The above lengths are at sea level and, therefore, subject to corrections for elevation. The above width of 150 feet is intended for the landing of one airplane at a time.

Tolerances below standard. -- For military airplanes: 300 feet (minimum width), 3,000 feet (minimum length).

Dimension of Approaches

To landing area. -- The approach area should provide an angle of approach from the boundary lines of the surface of the runway on the flight strips and extending in a cone-shaped space from the center of the runway. This approach area should be protected from encroachment by high buildings or other obstructions, by adequate zoning of future structures surrounding the flight strips.

Standard desirable. -- Thirty feet horizontal to one foot vertical for military airplanes.

Tolerances. -- Twenty feet horizontal to one foot vertical (minimum) for military airplanes.

Description of Desirable Characteristics of Terrain

The terrain may be uneven if not used by the airplane but the runway which is on a part of the flight strip must be smooth with not over a 1 percent grade for the entire area for use. The surface for the runway, whether paved or sod, should have adequate bearing characteristics. The treatment of the soil may be some form of stabilization such as the use of heavy grass turf with or without soil stabilization. (Permanent buildings will not be erected on the flight strip areas.)

Tolerances. -- One percent grade for military use.

Location with reference to Army air bases should be from 5 to 50 miles.

Loadings probable (maximum) for military airplanes:

(a) One wheel, 40 tons.

(b) Gross, entire airplane, 80 tons.

(c) Axle (2 front wheels), 80 tons.

(d) Maximum tire 108° square inches.

(e) Distance center to center tires, 30 feet.

Speeds

Landing. -- From 25 to 90 miles per hour (air speed).

Take-off. -- From 35 to 100 miles per hour (ground speed).

Prevailing Winds. -- The runway should be in direction of prevailing wind, when possible. Communication lines or utility poles on the highway right-of-way, at the end of a runway, should be placed underground. Other communication lines or utility poles should be placed on the highway right-of-way farthest from the flight strip area.

At present (1940) the C.A.A. recommends that there should be sufficient runways to permit landings and take-offs within 22-1/2° of true wind direction above 5 m.p.h. for 75% of time Class I airports, 80% of time for Class II and 90% of time for Class III and IV.

Earth Work

Earthwork operations as covered in the following discussion will include the grading of flight strips with particular attention to fill sections and the stablization of earth slopes.

Grading: In view of the fact that one of the few permanent features involved in the construction of a flight strip is the grading, it is of vital importance that a complete grading plan of the entire area ultimately to be included in the project be prepared which will take into consideration the contemplated finished grades. For this reason, the grading plan deserves careful attention. Drainage, surfacing, and landing-area flood lighting are all affected by the grades established for the landing area. Furthermore, in the event that the grading is executed in accordance with an unsuitable plan and additional grading must be done later, heavy costs of reconstruction of both drainage and surfacing are likely to occur before a satisfactory landing field is obtained.

One of the prime factors to be considered in preparing the grading plan is the maximum gradient permissible from an aeronautical standpoint. Excessive grades particularly make night landings more difficult. Longitudinal and transverse landing area and runway grades of not over 1-1/2% are preferable. Obviously it is not always feasible to adhere to this figure as a maximum, since wide topographical variations on a site often involve excessive quantities of earth moving. From the standpoint of aircraft operations alone, field grades should be held under 1-1/2% if possible.

In the consideration of ideal grades for a landing area, various factors, including the character of the soil must be given attention. If the soil is a very pervious sand or gravel, permitting the rapid absorption of rainfall, a perfectly level grade may prove the more desirable. If the soil is such as to necessitate the collection and removal of surface water, grades should be adjusted in so far as is feasible to provide for quick run-off, but not so steep as to cause erosion. There is a fine balance between these two extremes which varies with the type of soil occurring in each instance. A grade of about 1 percent under average conditions will be found to satisfy these requirements.

The principal controlling factors in the establishment of the grades are topography, soil, and climatic conditions. Each particular case should be designed to the conditions that prevail.

The layout of the runway has a very important bearing on the grades to be established for the landing area and should be definitely decided upon before establishing the grades.

Fills

The great variation in the nature of the sites to be selected for flight strips will produce a wide range in the character of the grading operations and the type of fills constructed. In some instances, fills, because of their depth, character of material, and method of placing, may be subject to a large amount of settlement, with disastrous effects to the drainage system and runways. The method of placing and compacting the material, therefore, should be given careful consideration. Means should be adopted to insure suitable compaction wherever it is feasible and economical to do so, and in those cases where such a procedure may be found practicable the drainage and surfacing program should be modified to allow for this condition. This, in some instances, would cause the construction of a system of hard surfaced runways to be deferred indefinitely. Under such circumstances, runways of some low-cost material might be adopted for temporary use and later utilized as a subbase for additional surface paving.

Under ordinary conditions, the placing of fills in thin layers and rolling will give satisfactory results. An improvement over this method consists of the addition of a suitable amount of water before and during rolling operations, depending upon the character of the material. The use of tractors and hauling equipment with track type treads and of sheep's-foot tamping rollers may prove advisable.

Fills made from material pumped from the bottoms of adjacent rivers or other bodies of water present quite a different problem. Before deciding upon such a method, the character of the material available should receive careful study to determine its suitability. Some hydraulic fills may require a very long period of time to attain sufficient firmness to serve as a safe landing area. In some cases, only part of the available material may be entirely suitable for the upper part of the fill. Should this be the case, the better material may be placed in the upper part of the fill in order to obtain a firm surface.

All fills should be properly compacted in accordance with the standard recognized practices after analyzing local soil conditions. In general, tamp or sheep's-foot rolling is recommended. Particular care must be used in securing compaction around culverts, man-holes, and similar structures not only to avoid future settlement but to provide proper bearing pressures for the structures. Occasionally it is desirable to compact cut sections, but here again local conditions govern. All sizeable boulders, portions of broken stone or concrete, and similar material used in heavy fills should be covered at least eight inches, and care should be used in placing such material so that it is not on the alignment of future drainage, sewer, or cable excavations or trenches. The use of trash or vegetation in fills should not be permitted.

While it is highly desirable, both from an aeronautical and a maintenance point of view, to obtain relatively flat embankment side slopes at the edges and ends of landing strips or field areas, a definite requirement may not be feasible so long as the full 500' width and the necessary length of the strip are provided, plus a reasonable shoulder width to insure proper marker and flood and boundary light protection. It is recommended, in instances of relatively high fills, that a ten-foot shoulder, ample for a service road, be provided outside the established strip boundary.

Stability of earth slopes is affected by moisture content, and therefore proper drainage may be a more satisfactory substitute for flatter slopes. Normal repose slopes, mentioned here for fill sections only, are:

Sand, clean	1.5 to 1	Gravel, sand and clay	1.33 to 1
Sand and clay	1.33 to 1	Soil, U.S. average	1.33 to 1
Clay, damp, plastic	2 to 1	Soft rotten rock	1.33 to 1
Gravel, clean	1.33 to 1	Hard rotten rock	1 to 1

All fill slopes shall be amply protected against surface water erosion by berms or gutters along the top of the slope to intercept surface water and prevent it from spilling down the slope. Surface water may be disposed of by properly constructed rubble or concrete spill-ways or by other suitable means of conducting the water to a subsurface drainage system.

The use of properly designed cribbing and retaining walls in fill slopes is permitted when site topography demands that every possible foot of available area be developed. Rip-rapping, sodding, sprigging, and landscaping of both fill and cut slopes are commendable in the interests of erosion control and appearance.

Excavation backslopes should be as flat as possible for the following reasons:

1. To reduce hazards to aircraft where deep cuts exist along landing strips.

2. To permit, during daylight, a full view of other strips or landable area by pilots maneuvering on or near the ground.

3. To assist in the control of erosion

4. To improve appearances.

5. To streamline (in snow states), by producing windswept areas to prevent snow drifts and subsequent drainage problems during thaws.

The repose slopes in cut sections are dependent upon the actual depth of the excavation at the boundary of the landable area and the elevation of the ground at assumed slope stake points beyond. Normally, when excavations exceed two feet at the boundary edge, the backslope should be established at not less than 5 to 1 unless adjacent terrain is such that extreme excavation costs result.

In conclusion, it is recommended that grading plans, wherever possible, be designed to carry surface water away from paved areas or building sites. A few hundred dollars expended in extra grading often saves thousands of dollars in drainage and paving installation and maintenance.

Drainage

It is difficult to summarize drainage design information in a few pages. At best, it will be possible to give only a limited amount of basic information.

It is believed that, as a basis for the design of drainage structures, sounder conclusions regarding the probable intensity and frequency of rainfall in a given area can be drawn from a study of observations, covering a 25 to 50 year period, at a number of stations, than from a study of observations at a single station for a similar period.

Precipitation data: For most sections of the country use of the ten-year, one-hour maximum rainfall curves represent conservative drainage design practice and is therefore recommended. While many large cities design drainage for golf courses and playgrounds on a basis of a five-year maximum, for more important areas where uninterrupted use is important, the ten-year maximum is widely used for current practice. Main trunk line sewers are frequently designed on a basis of 20 to 30-year maximum. The adoption of the ten-year period in airport drainage design appears to insure the safety of normal operations and to afford the best compromise between accomplishing the immediate removal of all water and proper consideration of cost factors.

The season of occurrence of the precipitation is another important factor which must be considered. In northern latitudes, considerable precipitation may accumulate on the ground as snow, and a large portion of this may suddenly be carried into the drainage system as the result of warm rains or high temperatures.

In the east central section of the country, as defined by the Ohio Valley Region, the precipitation is ordinarily quite uniformly distributed throughout the year, amounting to about 3" to 4" per month. Occasionally, however, a large portion of the precipitation falls through the winter as snow. When this occurs, it is quite possible that the run-off from melting snow may materially exceed the maximum from rainfall. In regions of heavy snowfall, the design studies must include the combined effort of heavy rainfall and melting snow on frozen ground.

Over the plains area of the northwest, the winter precipitation is relatively light, averaging only about 1" per month; but temperatures are lower so that considerable snow may accumulate. In this region, the probabilities of high surface flow or run-off are less than for other sections, however, because the temperature rises rapidly in the spring causing the melting and removal of the moderate snowfall before heavy spring rains begin. Moreover, the ground in the northwest usually freezes while in a comparatively dry state; hence conditions are favorable for considerable percolation during the following spring. In the southwest, very little snow accumulates but summer precipitation is more concentrated, resulting in high run-off from excessive precipitation over restricted areas.

Run-off: From the standpoint of drainage as employed under conditions typical of airport construction, that portion of the precipitation which percolates into the ground as the result of the permeability of the soil is of primary importance. Evaporation and transpiration losses may be ignored in the computation of surface run-off from an area as restricted in size as the average airport without seriously affecting design. The peak loads which the drainage system will have to handle will occur during and directly after periods of heavy precipitation, at which time the factor of evaporation and transpiration will be almost negligible. In a like manner, the percolation rate for any given soil will be greatly affected by the intensity of precipitation, as heavy rainfall is conducive to rapid run-off irrespective of the type soil on which it falls.

The most important factors to be considered in the design of a surface drainage system are the relative permeability of the various surfaces to be drained, the gradient over which the surface water must flow, and the rate of flow over these surfaces. The percolation through and the permeability of the paved runway surfaces, taxi-strips and aprons can be considered negligible, and for heavy rainfall the evaporation loss inconsequential. Some water is, of course, retained on the surface itself in depressions and other irregularities. Such deductions are purely a matter of judgment. For general practice, run-off from such surfaces can be considered 85% to 100% of the total rainfall. Sodded areas 10% to 25%. The maximum discharge from a sub-drainage system usually occurs 4 to 6 hours after a heavy rain of short duration.

For airport sub-drainage, subsurface runoff factors have been determined by experiment as equivalent to a certain depth of water to be drained away during a period of 24 hours. Normally this will be about 5/16" to 3/8" of water.

For normally shaped and graded landing strip areas, modified by the appropriate factors dependent upon coverage of vegetation and permeability of the soil, the percolation loss is the only deduction of consequence to be made in computing surface run-off, especially for rain storms of considerable intensity. In such areas, computation of percolation loss is necessary, although extremely close determinations are not possible from existing data.

Errors involved in such estimates are not particularly serious as far as surface drainage is concerned and would only result in surface ponding until the surface drainage system relived itself. Such a condition would not be especially critical unless the landing strip area sloped toward the paved runway and ponding water stood long enough to seriously soften the paving base and subgrade or interfered with the use of the area by aircraft. Construction which will result in conducting surface and subsurface water toward paved runways should be avoided, and where possible surface run-off should be directed away from the paved areas.

Character of soil: One of the most important considerations governing the location and selection of an airport site is the nature and composition of the soil and subsoil upon which it is to be built. For the economical development of the area for aviation purposes and especially for the life and durability of paved runways, taxi-strips and aprons, detailed knowledge of existing soil conditions, and especially its behavior in contact with water, is vitally important. Among the tests used to determine soil characteristics and behavior, the determination of the co-efficient of permeability is especially important.

A positive measure of the permeability of the soil offers the only rational method for the solution of drainage problems which, in the final analysis depend entirely upon accurate knowledge of soil drainability. This method of approach makes it possible to determine definitely the direct drain line spacing and discharge capacity to provide for the estimated flow in the system without unnecessary expenditures.

The soil texture, consistency and composition which may be measured by tests, intimately affect percolation and permeability and, in turn, the drainage problem. The completed soil investigation with interpretation of results should be available to the designer of the drainage system as it is the only adequate and reliable source of information of the most important factors in drainage design. Particular significance should be attached to the location of any impervious, or relatively impervious strata underlying the surface soil. The location of such impervious layers will have an important bearing upon the height of the water table, capillary rise and will influence the selection of drainage methods.

Natural drainage is one of the items of major importance in the selection of a flight strip.

Favorable conditions are manifest chiefly by the existance of a deep water table and by permeable and non-errosive soil. With such favorable natural conditions, the minimum amount of artificial means for the removal and disposal of surface run-off from the paved areas of runways, taxi-strips and aprons.

Since it frequently involves more valuable property, a site providing natural drainage may often require a greater initial investment than a poorly drained area, however, investigations should be carried considerably farther than a study of first cost in comparing sites to be selected for airport purposes. Even though another site being considered may be drained by artificial means at reasonable cost, the naturally drained site is, in most cases, preferable. Artificial drainage systems, however well designed and constructed, will usually require continued expense for maintenance through periodic inspection and cleanup.

The selection of a naturally drained area will relieve the project of a large expense for storm-water drainage systems and the consequent handicap of non-uniform operating conditions. Therefore, such a site is advisable, if it can be found to satisfy other considerations. Information available indicates the cost of drainage at some airports has been in excess of $400,000 and sometimes as high as $300 or $400 per acre, and it is obvious that too much emphasis can not be placed on the drainage question at the time of site selection.

Drainage requirements: A determination of artificial drainage requirements calls for a consideration of the following factors individually and also of their occurence in various combinations:

(1) Character and arrangement of soil layers compromising the soil profile.

(2) Slope of surface.

(3) Soil moisture - capillary, gravitational (including elevation of water table).

(4) Amount, frequency, intensity, duration, and season of occurence of heaviest rainfall.

(5) Temperatures.

The soil of some airports is of such a nature that the installation of subdrains or surface intercepting drains is of little or no value. If the soil is an impermeable clay, and one that will not become eroded if suitable slopes are used, and if there is no groundwater problem, drains help but little. This kind of soil would no doubt become soft and sticky on the surface during wet weather, and while a correction of this condition could not be accomplished by a form of drainage, the use of some granular material might prove effective in stabilizing it.

The types of soil profiles which determine, to a large extent, drainage requirements are:

(1) Uniform and pervious.

(2) Uniform and impervious.

(3) Pervious above; impervious below.

(4) Impervious above; pervious below.

(5) Irregularly stratified layers of pervious and impervious.

The first type would probably not require any kind of artificial drainage.

The second type would probably not indicate the need for subdrains because the lack of permeability of the soil might make their use ineffective.

The third type requires subdrains placed just above the impervious strata;unless this strata is below the elevation where the pipe would be placed if the impervious strata did not exist.

The fourth type Trenches, without pipe, cut through the impervious layer and filled with porous material would be adequate.

The fifth type would require drains tapping the water pockets.

The desirable conditions of surface slope and the influence of slope on drainage requirements have been discussed in the chapter on grading.

The necessity for removing ground water depends upon the elevation of the water table and the character of the soil. Stabilization of the soil may in some instances be accomplished by lowering the ground water elevation through subsurface drainage.

The rate of rainfall, the time during which this rate is continued, the size of the area, and the proportion of rainfall that reaches a given point within a given period of time are the principal factors that control the amount of water reaching a certain drain. The proportion of the rainfall that reaches a given point within a given period of time depends upon the nature of the surface, the grade of the surface, and the shape and size of the drainage area.

In some instances the need for a complete drainage system may be great only during a short period. If the airport is situated in a section where deep freezing is certain to occur, the drainage system must be carefully designed if it is to be effective during the period at which it is most needed. A difficult condition is created when the ground is frozen to a depth equal to or greater than the depth of the drain pipes, followed by a thaw and rain.

Soils and subsoils on sites requiring drainage, even though improved, are still usually inferior in load bearing and stability characteristics when compared with those on a naturally drained site and their presence is indirectly reflected in higher maintenance cost for all improved areas.

Adequate drainage is essential to the proper maintenance of paved runways. Experience history shows that more runway paving failures occur from unstable sub-soil conditions caused by lack of proper drainage than for any other reason.

The presentation here if detailed information for designing artificial surface and sub-surface drainage is impracticable because of the space required. Technical design information on drainage is available from the many drainage engineers' handbooks published on the subject. Other sources are A.S.T.M. standards and drainage pipe manufacturers' associations. However it may be desirable to present important drainage design information which had been recommended by various writers on the subject.

Special Design Information

Among the special drainage problems of airports and flight strips are: the size of the total area to be drained, the size of the non-permeable areas (runways and aprons) which must be drained, the speed with which drainage must be accomplished, the compressive loads which must be transmitted to drainage structures by the weight of plane wheels, and the added burden on existing municipal and state drainage systems, by the sudden run-off of water from airport landing areas.

Aldous advocates the use 1 to 1-1/2% transverse or crown to the runways. Make all areas slope away from the runway. Every effort should be made to control surface flow to adequately designed collecting and ponding basins. Subsurface drainage in impervious clay soil is not effective. A provision of subdrains for the purpose of lowering the water table is also good engineering practice, although a better solution might be a better location of the airport.

Be cautious in placing French drains in silty soils as soon they become inoperative.

Use the "Rational Method" of computing the amount of water to be handled by the component parts of the storm sewer system.

Rational Method $Q = C.I.A.$ in which

Q = runoff in cu. ft. per sec.

I = rate of rainfall in inches per hour.

C = runoff coefficient, stating the proportion of rainfall (I) that appears as runoff depending on type of drainage area.

A = drainage area in acres.

Values of C lie between .85 and .90. The determination of value C depends more or less on personal judgement.

The critical periods in a drainage system are cloud-bursts and the spring thaws. When there has been a heavy snow-fall and a thaw occurs the shallow surface and sub-surface drains are frozen and a congestion occurs. If a double system of drains is used with one at a secondary level which increases the amount of absorption of the ground and provides a drainage system below the frost line which creates a dry subsoil the congestion will be relieved.

Subdrains: Laterals for subdrains should be placed no farther apart than 25 feet with a porous back-fill which is designed to accomplish two purposes:

1. Quick drainage of all surface water and,
2. To intercept and lower the water table in order to reduce and control capillary water

See table II for depth and spacing of subdrains

French Drains: Runoff from umpaved areas is collected by French drains with perforated galvanized pipe from 8" to 21" diameter.

Inlets: Gutter inlets spaced 150" apart on runways, aprons and taxi-strips. Most interesting feature in the latter is the strip of 10 oz. burlap, separating the top 6" layer of gravel from the stone below.

Drainage Coefficients: Airport drainage coefficients prepared by the Armco Co. are presented in table III.

Surfacing

The decision as to the type of pavement to be employed must be determined from a consideration of local factors which include (1) sub-grade condition, (2) load requirements, (3) degree of permanency required, (4) availability of materials and equipment, (5) current and anticipated traffic (6) meteorological factors of average maximum temperature and pre-cipitation,

(7) funds available, and (8) local engineering practices.

The same essential engineering problems encountered in highway paving are encountered in the paving of flight strip runways. Certain special characteristics are required in the finished paved runways to satisfy aeronautical considerations, and only certain of the standard types of highway paving offer these characteristics. Of principal importance is a dense, well bonded surface course to prevent permeation of surface water and subsequent deterioration of the grade. It should be mentioned here that no special type of pavement, having exceptional qualities not found in the usual highway types, had been developed for runways, those designed and constructed in accordance with the accepted standard practices used in highway construction, and which provide the necessary special characteristics required for aircraft operations, will be found to be adaptable.

The design of standard highway paving takes into consideration the number of vehicles per day, or the frequency to which the paving is subjected to leads as well as the maximum load at any one time. The repetition of the load upon a runway is much less frequent than upon even a secondary highway, and the factor of fatigue is negligible in runway design. Therefore, the paving types which require the kneeding and compaction of traffic to maintain their density and life are obviously not so suitable for runways. To compensate for the absence of the compaction furnished by frequent traffic, softer asphalts and somewhat richer mixtures, combined with dense aggregates, are necessary to insure the density of the pavement and provide characteristics which resist the deteriorating effects of weather and climate. In this regard a tight, well bonded and sealed surface is of essential importance.

The color and light reflecting qualities of the runway are important considerations in the design to furnish the greatest amount of visibility for night landings and take-offs. Surface textures of a light color and those which have a high reflecting character are preferable.

In runway construction, the importance of high subgrade values is apparent, and the first essential step is grading and adequate drainage. Regardless of surface type, drainage should be as nearly perfect as possible and, if there is any question as to division of funds, it always should be resolved in favor of a dry subgrade. It is much better to have a completely drained runway, with an oiled gravel surface course, than the highest type pavement with poor drainage. In the latter case it is only a question of time before subgrade resistance will be lowered from entry of water, and rapid surface deterioration will occur; while in the first instance, the well drained earth grade affords a sound foundation upon which increased surface thickness may be added as warranted by increasing traffic.

Experience in England has taught that hard surfacing is almost necessary for take-offs, particularly for heavy gas and bomb loads. In the air corps experience indicates a hard surface is necessary to obtain fullest advantage of the best equipment.

Rough non-skid wearing surfaces are to be avoided because of the excessive tire wear they impose on landing aircraft. For concrete surfaces, those approaching a smooth troweled finish are most desirable.

Loose particles of stone, aggregate, gravel, etc., on runway surfaces drawn into the propeller disc during motor run-up or during the initial stages of the take off, have contributed to the failure of metal propeller tips. Propeller tip failures have caused a number of aircraft accidents as the effect of unbalance is often as severe as a shank or hub failure and may result in either throwing the engine or causing a forced landing because of excessive vibration. Even with perfect maintenance and servicing, a pilot cannot be sure that his propeller will remain in good condition during the motor run-up and take off when loose aggregate particles present on the runway surfaces may be drawn into the propellers.

This condition can be avoided by properly designing the surfaces in the case of new runways and be adequate and proper maintenance on existing runway surfaces.

All runways should have a suitable run-up section of strip at the end of each runway which is kept clear of loose gravel, cinders or other loose particles at all times. Paved surfaces on runways, taxi-strips, aprons and runway turn arounds should be selected from the well bonded, dense aggregate types.

Types of hard surfacing for runways which have been used successfully follow:

1. Sand clay
2. Gravel
3. Oyster shell
4. Bituminous soil stabilization
5. Cement soil stabilization
6. Macadam
7. Sand asphalt
8. Limerock
9. Concrete
10. Asphaltic concrete
11. Bituminous surface treatments, and others.

Firm turf surfaces may be used for airports with light and limited traffic in regions where soil and climatic conditions are favorable to maintenance of such surfaces.

Soil-cement is not recommended by the P.C.A. for heavy duty runways and aprons, but it offers a satisfactory surface for auxiliary and secondary runways and airports where first cost must be low.

<u>Turf:</u> In sections of the country where soil and climatic conditions

permit the growth and maintenance of firm turf surfaces, it may be possible for airports with light and limited traffic to maintain continous operation throughout all seasons of the year.

There is no one grass, or mixture of grasses, that can be expected to produce satisfactory turf on the landing areas of airports in all parts of the United States. In the northern half of the country, it has been learned that a mixture composed of 80 percent Kentucky blue grass and 20 percent redtop will answer fairly well for most purposes. In the Northeast, however, the proportion of redtop can be increased to good advantage, and on some of the acid soils such as are encountered in the New England States, a mixture of bentgrass and redtop should give good results.

In the blue grass regions of Kentucky, and adjoining States, there is probably nothing that will form a tougher turf than Kentucky blue grass.

In the humid northern part of the United States, some timothy could perhaps be added to the mixture to advantage. For the Southern States, there is nothing that is more generally adapted than Bermuda grass. For quickest results the Bermuda grass should be sown at the rate of 25 to 30 pounds per acre, and the mixture of Kentucky blue grass and redtop at the rate of about 100 to 150 pounds per acre. Good stands can be obtained with much less seed, but more time is required.

On the low, moist lands in the extreme Southeast, carpet grass ordinarily gives better results than Bermuda grass. In the arid and semiarid sections of the United States there are very few grasses that will grow without irrigation.

In the northern part of the Great Plains region, where the rainfall is not too limited, brome grass or crested wheat grass will doubtless serve the purpose as well as anything that is available.

Under irrigation, a Kentucky blue grass and redtop mixture should do well from Oklahoma north and Bermuda grass south of that general region.

A method of producing Bermuda sod, which has found favor in the southern portions of this country in the building of golf courses and in the grassing of shoulders of highways, is that of obtaining the grass from fields by plowing and raking and then planting by placing in shallow trenches, spaced about 18 inches to 2 feet apart, covering over with earth, dragging level and then lightly rolling. This method has the advantage of producing much quicker and surer results, with a more uniform covering of sod that can ordinarily be obtained by the seeding method. Where Bermuda grass can be obtained in large quantities, at no cost other than plowing, raking, and hauling, and where labor is cheap, this method of planting has its advantages.

From this it can be seen that practically every airport may require special attention to determine the grasses that are best suited for the particular case.

As soon as the young grass makes its first appearance, the serious business of maintenance begins. Some arrangement should be made to keep traffic off the turf until it has had an opportunity to gain a stand. This may be done by prohibiting the use of the entire field or by designating certain portions for use.

Under the strain of heavy traffic, turf is likely to become rutted, especially if exposed to alternate freezing and thawing. Because of the mud which is inevitable during the wet season, the maintenance of airplanes becomes more expensive, landings more difficult and accidents more numerous.

It is also true that while the turf surfaces provide a satisfactory landing area under certain favorable conditions, there are some conditions of soil, climate, and traffic, which can be met only with the installation of a specially prepared surface. There have been instances where airports that at first managed to get along fairly well with a turf field, later found that the increased traffic rapidly destroyed the grass and that some kind of artificial surfacing was necessary.

Paved Runways: The term runway paving is applied to the process of preparing a firm, stable, even, all-year, all-weather runway surface, free from dust or aggregate which may be blown or picked up by aircraft engine propellors and designed to support the static and dynamic loads occuring in the landing and taking off of aircraft. Hard surfacing may be divided roughly into two general types, rigid and flexible. In the rigid type it is assumed that all weak areas in the subgrade will be bridged and the load will be transferred to adjacent stronger areas. In the flexible type it is assumed that the pavement will be in constant contact with the subgrade and that load transmission to the subgrade will be more or less uniform.

Rigid type pavements include Portland cement concrete of varying thicknesses, with or without steel reinforcing, and certain asphaltic concretes, asphaltic or water bound macadams and soil-cement stabilization which may approach rigid characteristics. Flexible paving includes virtually all of the bituminous types of construction with cutbacks, emulsions, plant or blade mixes, built-up penetrations and bituminous soil stabilization.

Concrete Runways: Design data and recommended details for concrete airport pavements have been quite clearly discussed in a publication on the subject by the Portland Cement Association. Since this type of surface will be rarely considered in connection with flight strip construction, it is believed unnecessary to treat the subject further in this report.

Design Data For Paved Runways

The loads imposed by airplanes upon runways are generally divided into two classes -- static and dynamic. Current opinions and practices regarding the proper design factors for these two types of loads are covered in a general way in this chapter.

Static Loads: When an airplane is at rest, the sum of the loads which it imposes on a pavement obviously is equal to the gross weight of the plane. For design purposes it is usually customary to consider the gross weight of the plane as distributed between the two main wheels of groups of wheels, even though part of the load may be carried by the tail wheel, as in the case of the conventional airplane, or by the nose wheel in the case of a tricycle landing gear. For design purposes, the static wheel loads may therefore be taken as one half the gross weight of the plane.

The probable useful life of runway paving is important in airport design. In designing runway paving, it is necessary to consider not only the maximum gross weight of present day planes, but also the probable maximum gross weight of planes which will be in use during the life of the runway.

The oldest airport runway paving was built approximately fifteen years ago, and, therefore, it is difficult to estimate the probable life of the various types of runway paving. Figures on the average probable useful life of various types of paving in highway use have been obtained from the Bureau of Public Roads. Since the situation is not exactly parallel, any results or estimates must be an approximation. These figures are given in the table below.

Type of Paving	Probable Useful Life
High-types, such as Portland cement concrete, brick, block and bituminous concrete in rigid type bases	22 to 30 years
Low-type bituminous surfaces on flexible bases.	12 to 15 years
Low-cost untreated surfaces such as waterbound macadam, gravel and sand-clay properly maintained and serving within their traffic density.	8 to 12 years

Following are paragraphs from the letter received from the Bureau of Public Roads giving the information on the probable life of paving:

"We believe, too, that figures based on highway experience must be used with care when applied to airport problems. This is especially true with regard to traffic conditions on airport run-ways where traffic is dispersed over a relatively wide runway and not concentrated on a relatively narrow surface width as in the case on highways. Consequently, for example, bituminous surfaces on airports need a higher percentage of bitumen, preferably of a higher penetration to prevent their carbonization and resultant raveling, than do highways.

"In conclusion, we have found that estimates of pavement life are relative, not absolute, and that the highest type pavements have highest first cost, lowest maintenance cost, longest life, and highest salvage value; and that low-type surfaces have lowest first cost, highest maintenance cost, shortest life, and lowest salvage value."

Since these figures are estimates based upon nation-wide averages, it should be recognized that they may not apply in individual cases, as purely local conditions have such a decided effect upon the durability of pavements. These figures, even with their admitted limitations, do give some idea of

The probable period of time which must be considered in estimating the possible increase in airplane size and weight.

In designing airport and flight strip paving, it is necessary to consider the general weight classification of the planes which it is designed to accommodate. Future as well as present weight should be provided for.

Airplane gross weights for use in designing airport runway paving are contained in Table 4. These weights are the best available estimates of the weights of aircraft which may be anticipated during the probable life of the pavement. It is extremely difficult to arrive at a reasonable estimate, since in the case of a high type of paving this estimate should cover a period of from twenty to thirty years. Whether or not the gross weights shown in the table will be attained or exceeded within the estimated period of time remains for the future to disclose.

It appears probable that economic rather than structural limitations will determine the maximum airplane size. This statement applies to commercial planes only. Military airplanes are not subject to the same economic limitations as commercial planes and may, therefore, eventually become considerably larger. This fact must be considered in airport design, since the airports of the country must be constructed so that in time of an emergency, military aircraft can be accommodated without difficulty.

It appears that the size of commercial planes cannot economically exceed a certain limit if interest on the investment and amortization charges are considered. The demands for frequent service, in many cases, will make it more economical to operate a larger number of smaller units. The airplane gross weight at which this point will be reached is a matter of disagreement among engineers at the present time. Some engineers feel that under the conditions of present airline patronage by the public, commercial transport planes much in excess of the present day maximum of approximately 65,000 pounds will be found uneconomical to operate. On the other hand, if it is assumed that passenger traffic on the airlines will continue to increase each year at even the present figures, it would appear probable that commercial planes of a size considerably in excess of the present day maximum would be profitable to operate.

Included in Table 4 are values of tire pressures which may be used in airport paving design. These values are based upon current practice and also upon the assumption that tire pressures in excess of 75 to 85 pounds probably will not be used. Aircraft probably will be equipped with dual or multiple wheels when the gross weight of the plane increases to a point where pressure would exceed this value if a single tire were used.

Dynamic Loads: There is no complete agreement within the aviation industry as to the exact magnitude of the loads imposed upon runway paving by the vertical component of descent of the landing aircraft. The National Advisory Committee for Aeronautics had conducted a series of flight tests at Langley Field over a period of years. These tests are designed primarily to measure the stresses due to landing loads in the under-carriage and structure of the airplane rather than to measure the ground reaction. In these tests an accelerometer is mounted in the airplane as near as practicable to the center of gravity of the plane, and from the readings of the instrument, an estimate is made of the magnitude of the ground reaction.

An investigation was also made of tests conducted by the Bureau of Public Roads to determine highway impact factors. As a result of the consideration of these tests and the N.A.C.A. series of tests, the impact factor of (2) as a theoretical design factor to be applied to the gross weight of the plane was evolved.

As the result of practical experience, however, it is now generally accepted that the employment of impact factors in runway design, to provide for dynamic loads, may be discounted so long as the design is adequate to support the maximum static loads anticipated upon a given runway.

This apparent discrepancy between the theoretical impact factor (2) and a negligible impact factor is predicated on the deflection of the tire itself under the landing shock, and the entire absence of a direct impact at the moment of landing contact. Tests conducted by the tire manufacturers indicate that the average airplane tire deflects under landing impact by an amount which materially increases the contact area between the tire and the paving. This increase in tire contact area is sufficient to partially justify the reduction of the impact factor.

Impact loads are of extremely short duration since aircraft travel with a velocity of from 70 to 90 miles per hour, or from 102 to 132 feet per second, in landing.

The suggestion has been made that in the case of rapidly moving loads on flexible pavement a situation exists similar to that of thin ice which will support a skater if he is moving rapidly enough, but which will break under his weight if he should stop. It is believed that further research of this problem will be very productive.

Pavements at loading and warming-up aprons and turnarounds at the ends of the runways should be of the highest possible type because of possible damage from the heavy shearing loads occasioned by short radius brake turns and from drippings of gas and oil.

Surface thickness: The following thicknesses have been specified, based upon laboratory tests.

Subgrade P.I.	Sub-base Thickness	Base Thickness
30 or less	6"	5"
30 to 40	4"	8"
Over 40	4"	10"

Another design method for determining surface thickness is the use of Down's formula:

$$T = \frac{0.564W}{S}$$

T = thickness of pavement required.
W = wheel load.
S = load bearing value of subgrade.

The modification of the above formula by B.E. Gray subtracts from the calculated required thickness the radius of the equivalent tire circle.

Crowns: Crowns and transverse gradients should be sufficient in pitch to expedite surface water runoff. This must be emphasized in states where freezing occurs because of possible ice damage to aircraft surfaces.

RUNWAY CROWNS

Runway Width	Minimum Crown*	Recommended for Average Conditions
100'	6"	9"
150'	9"	12"
200'	12"	18"

*Recommended only for areas where rainfall is light and for impervious types of pavement.

RUNWAY CROWN POINT COORDINATES

Runway Width	Dist. of C.L.	Crown Elev.
100'	0'	0.62'
	25'	0.37'
	50'	0.00'
150'	0'	0.94'

Runway Width	Dist. of C.L.	Crown Elev.
150'(cont.)	25'	0.74'
	50'	0.37'
	75'	0.00'
200'	0'	1.25'
	25'	1.11'
	50'	0.74'
	75'	0.37'
	100'	0.00'
300'	0'	1.88'
	25'	1.73'
	50'	1.48'
	75'	1.11'
	100'	0.74'
	125'	0.37'
	150'	0.00'

". . . . . . The crown is parabolic over the crest with a continuation to the sides on a grade less than 1.5%."

"The grades lengthwise of the runway are also less than 1.5%."

Camouflage

The basic principles of camouflage should be considered in the location, design and construction of flight strips. This is important because flight strips are being constructed primarily from a military standpoint. Experience in England and Germany show the importance of proper camouflage.

In the present war in Europe it is reported that the Germans are also using runways for their aviation fields that look as if they were a part of the highway. Usually these runways - laid out and constructed in areas which we call "flight strips" - are located near small villages and appear to be side roads leading into the main highway. If the highway is of concrete, then the runway is covered with a thin layer of white sand to conform to the same color of the highway. When the highway is of asphalt, then the runway is given a darker color. These areas serve as flight strips for the landing and take-off of aircraft, when a strong cross wind is blowing at right angles to the highway or the highway is not of sufficient width or straight enough to be used as a runway. The hangars may be a little distance away from the "flight strip" area and are often surrounded by big trees. From the air it is said they look more like big barns than hangars.

A detailed discussion of Modern Camouflage will be found in Part V under the subject of Camouflage.

PART V

CAMOUFLAGE

In times of emergencies, flight strips located in strategic areas will no doubt be camouflaged as a protection against bombing. The basic principles of camouflaging have been included in this discussion because it is believed that such principles should be considered in the selection of the flight strip sites and applied to a certain degree to the finished project.

The following discussion is based upon experiences presented by Army Engineers.

What is Camouflage?

No entirely satisfactory definition of camouflage has ever been written. It may, however, be described as the science of confusing the identity of an object for the purpose of deceiving the observer. Camouflage, or "protective concealment", may be accomplished by (1) reduction of visibility, (2) complete concealment, (3) changing the apparent identity of the object, or (4) the use of dummy or decoy targets.

There is no magic or mystery to modern camouflage. It is based upon techniques developed by experimentation and experience. It combines the knowledge of many fields of endeavor, including design, construction, art, and engineering. Many professions and many industries have made great contributions towards the advancement of camouflage, and there is yet much to learn.

How Does It Differ From Camouflage During World War I?

When thinking of camouflage, most people recall to mind the battle front photographs of the last war illustrating sniper posts or observation posts, which were almost invariably located in fake tree stumps or in the carcasses of dummy dead horses made of papier mache. The zigzag or "dazzle" painting on ships, a technique still useful on occasion, also lingers in the memory. This type of camouflage was designed to conceal primarily against observation on the ground or from observers in low altitude captive balloons.

In modern times our problem is very different. Hostile bombardiers, observers, and photographers are often many thousands of feet up in the air. They are looking for, and can only see, large installations and factories, arsenals and similar large targets; the single individual soldier and his camouflage are of little interest to them.

What Are We Protecting Against?

In the event of emergency, consideration should be given primarily to precision bombing in this country. The long distances involved would probably make area bombing, blitzkrieg tactics using a large number of bombers, the exception rather than the rule. Also, the question of concealment against aerial photography may be considered of secondary importance. Even though a target may be easily discernible in an aerial photograph, it is safe from precision bombing unless the bombardier can actually see the target in his bomb-sight.

In precision bombing the bombardier must actually sight his objective or a very close reference point directly in the line of flight and track it for an appreciable period. His speed is so great (up to 400 miles per hour) that he will generally have only 30 to 45 seconds in which to do this - unless he makes a return flight. He must sight and bomb his target from an oblique angle from 15 to 50 degrees with the horizontal. Anti-aircraft artillery and fighter planes will tend to keep enemy bombers at elevations of at least

10,000 feet and possibly even at heights of 35,000 feet or more.

The bombardier's task is therefore not an easy one, even without the added handicap of camouflage because of the speed, high elevation, and distance from the target which may be in excess of six or eight miles. This explains why camouflage stops short of complete concealment (in other words, any reduction of visibility of the objective) may be justified as a defensive measure.

How Does The Bombardier Locate His Target?

Landmarks: A bombing target is most easily located by means of landmarks in the immediate vicinity. These may include easily identified coast line features, lakes, rivers, mountains, and man-made installations including towers, highway intersections, race tracks or large easily identifiable buildings. If such a landmark is within a mile or two of the target, it may be used as a direct reference point in the bomb-sight, even though the target itself is completely camouflaged. Thus, it is evident that when selecting sites for new construction the presence of landmarks is an important consideration. Likewise, in the concealment of existing installations it is sometimes necessary to camouflage nearby landmarks, as well as the target itself.

Form, Bulk and Shadow: This may be summed up briefly by the statement that there are no straight lines or right angles in nature. Therefore, any straight roof lines, tall chimneys, straight roads or absolutely straight waterways are a give-away. By the same token, all camouflage efforts to duplicate nature must avoid the use of straight lines and straight edges wherever possible. In many instances, however, a rectilinear design will be desired to simulate an urban pattern.

Sometimes bulk alone, even with irregular edges, reveals the target. Large bulks or areas must be treated to give the appearance of being broken up into smaller units.

Of equal, if not greater, importance are shadows. Frequently the straight black shadow cast by the target is more visible than the target itself. Shadows may be broken up at source with the use of nets and screens or by suitable silhouettes over or on the structures. Even more effective, however, is the use of trees and other plant materials to absorb the shadows on the ground. These same materials are also very effective in breaking up the square lines and outlines of the buildings themselves.

Texture: Texture may best be defined and demonstrated by the reflection of light on the top of a silk hat. When the nap is rubbed smooth the surface appears glossy and light. When the nap is rubbed the wrong way, however, the entire effect changes; each hair casts a minute shadow and the effect of the surface is rough and dark. Another example is the way in which various crops in cultivated fields can be identified from the air by their texture alone.

This same effect must be considered when camouflaging an installation. For example, it is not completely effective to paint a flat surface, such as a roof or a roadway, to simulate grass even though the color may be an exact match. From the air the difference in texture will be clearly discernible. Artificial textures may be created by the use of garnished nets (the hanging ends of the garnishing material produce the necessary shadow) and by adding rough particles for texture, such as shavings, ground rubber, wood chips, and slate roofing granules, to the flat surfaces to break up their complete smoothness.

A modification of texture is the use of dull mat finishes in all camouflage painting, to reduce the specular reflection of light on the surface. Results similar to those obtained with lustreless finish paints may be achieved by throwing dust or sand on the painted surface before it dries.

Color: Color is probably the least important consideration. The clarity of colors tends to fade to a considerable degree when viewed from higher altitudes, because of haze and distance. In general, the color and tone of the surrounding terrain should be duplicated as far as possible on the target, and any pattern which occurs in the landscape should be carried over the installation by means of paint or actual construction.

What Are The Three Stages Of Camouflage?

Minimum Job or "Toning Down": Paint is the principal means of accomplishing this type of work. Although little actual concealment is achieved, the results may justify the efforts because of the slightly increased difficulty which the bombardier encounters in locating the target in his bombsight.

The Average Job: The next step may involve the introduction of false shadows and false forms to destroy revealing outlines. Simple construction, including the use of salvaged lumber, chicken wire, cheap textiles and other available materials may be used, together with the planting of trees and other natural materials. Flat surfaces may be textured by the addition of crushed rock, sand, or ordinary roofing granules.

The Total Job: The total or all-out camouflage includes complete duplication of the patterns and tones of the surroundings. This may involve the building of false roofs and other complex construction, real, or artificial trees on roofs, and in some cases, placing the installations underground.

The cost and effort of a total job are justified only where the target is of extreme importance to national defense.

How Are Camouflage Plans Prepared?

Competent architectural, painting, engineering and landscaping services can probably handle a majority of jobs, if experienced camouflage assistance is not available. Aerial photographs and ground plans will be required, and for more complex structures a scale model may be desirable. After the camouflage is completed, it should be checked frequently by aerial observation and photographs to determine its effectiveness at various times of day and during the various seasons.

It is obvious that some kind of provision must be made at the time of construction and in conjunction with camouflage operations for either emergency or permanent lighting facilities. A brief discussion of general airport lighting is presented in part VI.

PART VI

LIGHTING

An unlighted landing area is obviously of little use after sundown and therefore reliable airport lighting is necessary if the flight strips are to be used for day and night service.

Under war time operations for military purposes flight strips will undoubtedly be lighted by special portable lighting apparatus furnished by the army. In peace time, the basic minimum requirements for lighting equipment established by the Bureau of Air Commerce will no doubt prevail. Since lighting equipment has been standardized by the Bureau of Air Commerce and the succeeding Civil Aeronautics Board and that complete factual data concerning the same can be obtained from them, it is believed that only a short discussion of the subject is necessary in this report.

The distinctive function of airport lighting can be considered as falling into two main categories;

(1) Airport identification lights and (2) aids in landing on and taking off from the airport. And a third, less distinctive division is (3) miscellaneous lights.

Some of the lights have functions falling into more than one division and must be considered as having a double function. The classification by divisions is as follows:

Type of light	Division
1. Airport beacon	1
2. Illuminated wind-direction indicator	2
3. Boundary lights	1-2

Type of light	Division
4. Range lights	2
5. Contact lights	2
6. Approach lights	2
7. Obstruction lights	2
8. Roof marking	1
9. Ceiling projector	3
10. Landing area, flood lights	2
11. Traffic lights	2
12. Apron and exterior flood lighting	2-3
13. Interior lighting	3
14. Temporary marking	2

The category listed as Number 1, or identification lights, has its primary function in the indication of the location of a lighted landing field. The lighting units under Category Number 2, or aids, serve to aid the pilot in landing and taking off from the field. The third category relates only indirectly to flight operation.

The varying needs of lighting at individual landing fields must be thoroughly studied and airport lighting experts called in if the most effective use is to be obtained from the money available.

As a final consideration in flight strip construction, thought must be given to future maintenance operations both in peace and war time. A landing field must be properly maintained at all time or else abandoned. Maintenance as applied to flight strips is explained in part VII.

PART VII

MAINTENANCE

A landing field not properly maintained at all times may be more dangerous than no field at all because the existence of a field implies adequate landing facilities.

The all year maintenance of flight strips becomes an obligation of the State Highway Departments and funds will be necessary for doing this work. A suggested source of revenues is from concessions located at improvement areas containing flight strips. Flight strips with such facilities would have greater value.

Maintenance Of Right-of-way And Runway Surface

The general maintenance of flight strip right-of-way and runway surface is identical with that of a modern highway and its appurtenances; therefore it is believed that further discussion of the subject in that respect is unnecessary since the maintenance divisions of highway departments are well equiped and experienced to do the work. However, in winter maintenance the snow and ice problem is handled in a different manner.

Winter Maintenance

From experience it has been found that the best way to handle snow deposition on an airport is to pack it in place on the runways. This is accomplished by dragging rollers over the snow until it becomes thoroughly packed and will not be displaced under airplane wheel loads. It is evident that snow characteristics will govern to a certain extent the type of equipment and method of compaction.

A snow packing roller used by the Allegheny County (Pittsburgh Pa.)

Airport is described as follows. The roller is 8 feet in diameter, 10 feet long and weighs about 1000 pounds. It is built around 5 circular wooden frames which turn on a 2 inch pipe axle. A light steel frame connects the axle to a wooden hauling tongue. The ends of the roller were closed. The outside logging is made of 1" x 4" boards. Pulled by a light truck at normal speed it reduced the depth of snow from 6-1/2" to 2" in one pass.

Emergency Maintenance.

During war emergency it would be the duty of highway departments to have available equipment and materials to move debris, fill holes, and repair runway surfaces in case the flight strip should be bombed and temporarily put out of service.

The design, construction and maintenance of flight strips should include certain consideration to necessary utilities which will eventually become a part of the whole project. Such utilities are discussed in part VIII.

PART VIII

UTILITIES NECESSARY TO OPERATE FLIGHT STRIPS UNDER SPECIAL CONDITIONS SUCH AS, WAR EMERGENCY, RECREATION USE, COMMUTING BASE

Since it is planned that flight strips will ultimately become a part of a general state and national airway plan they will be eventually equiped with such public utilities as phone, electricity and water for the convenience of private users. Provision should be considered for their future installation.

In certain locations, especially in metropolitan areas and recreation centers, the flight strips will become popular as commuting bases for privately owned planes. Therefore, proper steps should be taken in the design of flight strips for the installation of fire fighting equipment and first aid facilities as well as, shelter and storage for planes, sanitary measures for concessions, rest rooms and other buildings, and provision for supplying airplane fuel, oil and repairs.

Certain aeronautical details must be taken into consideration when designing flight strips and airports. Part IX contains a discussion of the more important ones.

PART IX

AERONAUTICAL DETAILS

In preceeding parts emphasis has been placed upon the design and construction of flight strips. However, there are certain aeronautical details which must be considered as being part of the master plan. These details include such factors as airway legislation, property rights in upper air spaces, zoning, approach zones, and air markings.

Aeronautical Laws and Regulations

For intra-state airway state legislation is required. For example, in Massachusetts in addition to legislation relating to municipal fields, the State Department of Public Works is authorized to establish airports, landing fields and landing strips.

The Air Commerce Act of 1926 defines a civil airway as "a route in the navigable air space designated by the Secretary of Commerce as a route suitable for interstate or foreign air commerce."

The establishment and regulation of airports is the province of the state and not of the Federal authorities.

Property Rights in Upper Air Space

Over congested parts of cities, towns and settlements, except for emergency landing, flying shall be not less than 1000 feet high. Elsewhere, not less than 500 feet.

By "court decision" a land owner owns so much of the space above him as he uses, but only as long as he uses it.

Zoning

"Airport zoning is today accomplished by varying city, county and state ordinances and statutes. The glide path of the plane as measured from the edge of the landing area and above which no structures are permitted to project, was only 7 to 1 in early ordinances whereas most of the ordinances now are in effect that the glide path is 15 to 1."

". . . .Zoning regulations are becoming increasingly strict, both as to height and distances from airport."

Many states have zoning enabling acts permitting the control of height of buildings and use of land which could readily be applied to the protection of an airport if such protection is compatible with general use in the neighborhood.

"The Civil Aeronautics Board has created several committees on airport zoning and eminent domain for the purpose of revising and standardizing ordinances. . . . ."

Approach Zone

"An 'approach zone' is a trapezoidal area having a width of 1000 feet at the boundary of the airport and broadening to a width of 4000 feet at a distance of 2 miles from the boundary, the centerline being a continuation of the center line of the landing strip. It is expected that the ratios cited (see I A-1 glide paths) will be required only with respect to the "approach zones" of the airport". . . . ."For all other areas about an airport it is expected that the glide path will be a minimum of 7 to 1 at sea level."

Air Marking

"Air marking is the aeronautical term applied to town names, highway route numbers, directional arrows etc., painted on hangers, roofs of factories, railroad stations and other conspicuous places. As fliers often follow important highways when traveling unfamiliar territory, marking these highways with state names and route numbers is particularly valuable.

The Air Commerce Act of 1926 provides among other things, "Radio range beacons for directional guidance", and "Radio markers beacons for assistance in locating strategic points, such as intermediate landing fields and in many cases giving directional guidance over short distances."

Air routes should be classed as tentative until they are tested by actual flights. Since no lighting or radio facilities will be provided for emergency landing fields, air marking is the only aid to navigation which can now be provided.

In Michigan, airway marking is especially important because the recreation interests are anxious to attract visitors from all parts of the country. For fliers unfamiliar with the state it is essential that the airways be clearly marked to direct those who stray off the highways.

The markings should be as simple as possible, consistent with the information to be conveyed. They should be of a permanent nature, economical to construct and maintain and should be placed in accordance with a fairly definite system, in order that pilots may know where to expect them. When possible, include the following: the name of city or locality, a meridian marker, nearest airport with rating--chrome yellow characters on a dead-black background are the most effective.

The height of letters used for name of city should be from 10 to 30 feet as available space may permit. Under no circumstances should lettering be less than 6 feet high. It is more desirable to use abbreviations than reduce size of lettering.

APPENDIX NO. I

Excerpt from - Public Law 295 - 77th Congress, Chapter 474, 1st session S-1840

Section 8. Flight Strips. - In order to insure greater safety for traffic on the public highways by providing additional facilities in connection therewith to be available for the landing and take-off of aircraft, the Commissioner of Public Roads is authorized to provide, in cooperation with the Army Air Corps, for studies and for the construction of flight strips adjacent to public highways or road-side-development areas along such highways. The acquisition of new or additional lands necessary for such projects may, to the extent determined by the Federal Works Administrator, be included as part of the construction thereof and Federal funds shall be available to pay the cost of such acquisition. For carrying out the purposes of this section, there is hereby authorized to be appropriated during the continuance of the emergency declared by the President on May 27, 1941, in addition to any funds that may be available under any other appropriation, the sum of $10,000,000, which shall be available, without regard to apportionment among the several States, for paying all or any part of the cost of such projects.

Excerpt from - HOUSE BILL no. 17 - Michigan 61st Legislature.

(G) Property deemed by the Board or Commissioner to be necessary for the construction, adjacent to the highways, of flight strips for the landing and take-off of aircraft in order to insure greater safety for traffic; for the purpose of uniformity the size, location, layout, lighting and markings of such flight strips shall be in conformity with rules and regulations to be prescribed by the Commissioner.

TABLE I

EFFECT OF ALTITUDE ABOVE SEA LEVEL ON AIRPORT SIZE

Elevation	Class I	Class II	Class III	Class IV
	Runway Lengths in Fact			
Sea Level	1800	2500	3500	4500
200	2040	2840	3980	4860
400	2340	3250	4550	5250
6,000	2690	3740	5230	5670
8,000	3120	4350	6070	6150
10,000	3660	5090	7120	7120

TABLE II

RECOMMENDED DEPTH AND SPACINGS OF SUBDRAINS

(From Armco "Manual of Airport Drainage")

Soil Classes	Percentage of Soil Separates Sand	Silt	Clay	Depth of Bottom of Drain ft.	Distance between Subdrains ft.
Sand	80-100	0-20	0-20	3-4 2-3	150-300 100-150
Sandy Loam	50-80	0-50	0-20	3-4 2-3	100-150 85-100
Loam	30-50	30-50	0-20	3-4 2-3	85-100 75-85
Silt Loam	0-50	50-100	0-20	3-4 2-3	75-85 65-75
Sandy Clay Loam	50-80	0-30	20-30	3-4 2-3	65-75 55-65
Clay Loam	20-50	20-50	20-30	3-4 2-3	55-65 45-55
Silty Clay Loam	0-30	50-80	20-30	3-4 2-3	45-55 40-45
Sandy Clay	50-70	0-20	30-50	3-4 2-3	40-45 35-40
Silty Clay	0-20	50-70	30-50	3-4 2-3	35-40 30-35
Clay	0-50	0-50	30-100	3-4 2-3	30-35 25-30

TABLE III

AIRPORT DRAINAGE COEFFICIENTS

(From Armco "Manual of Airport Drainage")

Required Capacity of a Drain in Cubic Feet Per Second to Remove Various Depths of Water in 24 Hours (Elliott)

Depth in Inches		Capacity, Cu. Ft. per Sec.	
Fraction	Decimal	Per Acre	Per Sq. Mile
1	1.000	.0420	26.88
15/16	.938	.0394	25,20
7/8	.875	.0367	23.52
13/16	.812	.0341	21.84
3/4	.750	.0315	20.16
11/16	.688	.0289	18.48
5/8	.625	.0262	16.80
9/16	.562	.0236	15.12
1/2	.500	.0210	13.44
7/16	.438	.0184	11.76
3/8	.375	.0157	10.08
5/16	.312	.0131	8.40
1/4	.250	.0105	6.72
3/16	.188	.0079	5.04
1/8	.125	.0052	3.36
1/16	.062	.0026	1.68

TABLE IV

DESIGN DATA FOR PAVED RUNWAYS

Recommended Standards	Class 1	Class 2	Class 3	Class 4
Static design loads for runway and apron paving based on present day aircraft. Load considered destributed equally between two main wheels or sets of wheels.	No paving recommended	30,000#	60,000#	100,000#
Probable future (10 years) maximum static gross loads to be considered in the design of runway and apron paving and drainage structures.	No paving recommended	60,000#	150,000#	300,000#
*Theoretical design impact factor for paving to be applied to gross weight.	No paving recommended	2	2	2
*Recommended design impact factor to be applied to paving loads per unit area.	No paving recommended	Practical experience indicates any design adequately supporting maximum anticipated static loads will be sufficient.		
Probable range of static airplane tire pressures.	10 to 25# sq. in.	15 to 50# sq. in.	30 to 75# sq. in.	50 to 85# sq. in.

*Allowance for impact in paving design may be made in terms of gross load or applied load per unit area. Both allowances in combination, however, should not be used. Wherein the anticipated maximum static load cannot be reasonably forecast, the use of an impact factor of not to exceed 1-1/2 applied to loads per unit area is recommended.