FEASIBILITY AND COSTS OF AN ELEVATED STOLPORT TEST FACILITY AND ITS POTENTIAL FOR METROPOLITAN USE

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This paper describes the results of a study of the feasibility and costs of building an elevated STOLport test facility that would eventually be expanded for revenue service. Engineering analyses were made of many structural schemes. Two were chosen for more rigorous study to develop costs for STOLport test facilities at 2 sites. The estimated construction costs of a metropolitan area site test structure are $22 million. The costs of the containment and arrestment systems and the land acquisition could add $2 to $10 million. The expansion of a test facility into a passenger-carrying facility with commercial joint use of the space below the flight deck was conceptualized to aid the Federal Aviation Agency in developing a policy for determining proportional participation in capital funding between the federal government and local authorities or private developers. The study concluded that there would be marginal savings in construction cost to those locating in the STOLport as compared to an alternative location. The potential for reducing or recovering the cost of an elevated STOLport through joint use is primarily in the dual use of the land area. The cost of the STOLport flight-deck support system would not change significantly if it were constructed as a free-standing structure, e.g., over a transportation corridor, or combined with a joint-use building.

•RECOGNIZING a particular confluence of different transportation modes and facilities on New York City's North River Chelsea waterfront, Bakke (1) proposed in 1969, "[If] we were to take a major section of real estate and build on it one mammoth structure tailored to serve the kinds of businesses that are suffocating in the city today, and locate this structure at a key transportation hub for easy accessibility by rail, wheel, and air... [and] then... were to ask the occupants of this superbuilding to share a common roof..., we would have a new tailor-made vertical- or short-takeoff and landing (V/STOL) airport capability." Bakke also detailed the potential for such an intermodal STOL facility to maximize access to concentrated downtown areas and the role such a facility could play in their continued economic vitality. Subsequently, however, efforts to develop STOL service have been frustrated by the lack of accepted definitions regarding facility design and aircraft performance. To overcome part of this lack, the Federal Aviation Agency sponsored an industrywide hearing in 1970 that led to the publication of design criteria (4). A nominal 2,000-ft (609.6-m) runway length and a combined runway and safety area width of 300 ft (91.4 m) were established.

The key to intercity STOL service is the downtown site, particularly one such as lower Manhattan. High land costs and development pressures in town centers tend to support Bakke's contention that a STOLport should be elevated, most likely atop a multilevel, multiuse structure. There is, however, little experience for developing a satisfactory design or assessing the costs of such a structure. Research on STOLports will also apply to off-shore jet ports, for they too require elevated structural decks. Indeed conducting flight operations from space-limited, elevated-deck facilities is one of the major challenges facing aviation in serving urbanized areas.

Flight operations from an elevated flight deck essentially have only one useful precedent: aircraft carrier operations. But the operations are different in 3 fundamental ways: Carrier operations are assisted takeoff and landing and involve a complement of complex expensive equipment; the carrier will steam into the wind to produce optimal aerodynamic conditions for takeoff and landing operations; and the mission-oriented military nature of carrier operations is such that the costs and risks accepted are higher than those that could be accepted in market-oriented, civilian STOL operations. The attention that the problem of an elevated flight deck for civil STOL operations has received indicates the need for a flight test program to develop experience with such a facility.

STOL DEVELOPMENT PROGRAM

Among the key concerns in the Federal Aviation Administration program for the development of quiet short-haul intercity air service is that of the operational feasibility of an elevated STOLport. Three main questions were addressed in this study.

1. What is an appropriate design for an elevated structure that could be used at the National Aviation Facilities Experimental Center (NAFEC) for a program of flight testing off an elevated deck? What would such a structure cost?
2. What is an appropriate design for a comparable structure for a flight test program in a downtown metropolitan site? What would be its cost?
3. What are the land requirements and urban development and environmental impacts of a downtown elevated STOLport for passenger service and with joint commercial uses in the lower portions of the structure?

An elevated flight operations test program is needed to provide the necessary data for certification criteria, operational criteria, aerodynamic effects and crosswind control, pilot visual cues, visual and electronic landing aids, noise level measurements and abatement procedures, STOLport layout criteria, aircraft containment and arrestment operational criteria, initial and recurrent pilot training, facility requirements, passenger acceptance, structural considerations, and aircraft certification and systems testing.

ELEVATED STOLPORT STUDY

A study was performed on the structural feasibility and cost of an elevated flight-deck structure to facilitate a test program to aid the FAA in formulating standards and criteria for aircraft, facility, and appurtenances; to aid manufacturers in the development of aircraft and facility hardware; and to aid operators in the development of suitable sites.

Design Analysis for Facility at NAFEC

The first consideration in the study was the design analysis for a low-cost structure at the NAFEC site at Atlantic City, New Jersey. Removed from metropolitan pressures and supported by extensive testing resources, such a facility would provide an ideal environment in which to gain the necessary knowledge to establish standards and criteria. The estimated construction cost of a test structure that would be 300 ft (91.4 m) wide by 2,000 ft (609.6 m) long by 100 ft (30.4 m) high and that would accommodate a 100,000-lb (45 400-kg) gross weight STOLcraft was $18 million, which is less than a structure at a metropolitan site where heavier aircraft would have to be accommodated.

Design Analysis for Facility at a Metropolitan Site

The second consideration involved a STOLport test facility to be located in a typical large metropolitan downtown area. The advantage of such a concept is that the test facility costs could be subsequently amortized by future expansion to a passenger facility. The difficulties, however, must be recognized:

1. The vast test support resources of NAFEC could not be used;
2. Greater costs of the test structure are necessitated by STOLcraft in the 150,000-lb class;

3. A test program in such a locale, even if permitted, would be constrained by considerations of public reaction and safety;
4. The duration of testing would be limited, and there would be no facility for recurrent or advance testing; and
5. Land would have to be acquired.

Some of these considerations are reflected in the higher development costs of a prototype metropolitan STOLport test facility. Because the metropolitan site is believed to be of interest to a wider audience, this paper emphasizes it rather than the one at NAFEC.

Implications of Urban Site and Joint Development

An analysis was made of the space requirements below the flight deck for passenger terminal and other ancillary functions within a structure 100 ft high. The results were used in determining the proportional use of the area below for the aviation facility and the joint commercial uses that would share space in the structure. Analysis was also made of its impact on the urban environment.

ELEVATED STOLPORT AT METROPOLITAN SITE

Site Choice

A hypothetical metropolitan site was evaluated for its potential as an interim use test facility that, after a successful test phase, could be expanded to serve as a passenger operational STOLport. The reasons for evaluating this approach were that the cost of building a test facility is a substantial part of the cost of an operational facility and that, in addition to the aeronautical problems, a greater measure of the problems of operation in an actual metropolitan environment could be experienced and evaluated. Some disadvantages of this strategy have been noted above. The value of such an approach is in determining the type of problems that an authority or municipality might anticipate in planning such a facility and developing a preliminary means of assigning areas to joint users that might share the costs of construction. Further, the FAA could use such an analysis to develop a policy for proportional participation in funding such facilities.

Facility

The hypothetical metropolis has a population of 2 million and is located in a large urbanized region that has heavy intercity traffic. Other assumptions are that 50 percent of the air traffic is short-haul, the STOLport is the primary airport serving the city, and the facility attracts about half of the short-haul market. This was computed to involve $\frac{1}{2}$ million passengers initially, 2 million by 1984, and $5\frac{1}{2}$ million by 1990.

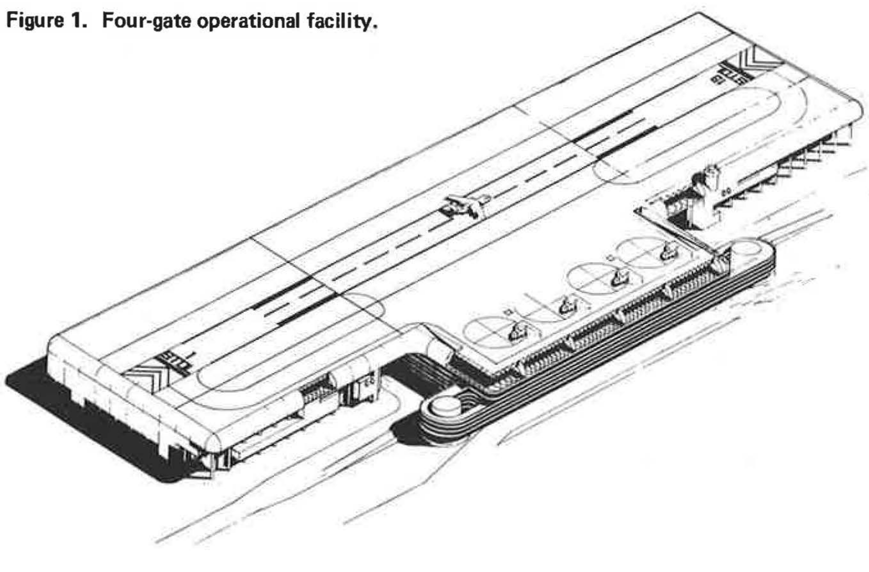
The test facility is essentially that developed for the NAFEC site, with the following 3 differences:

1. In the absence of the NAFEC capabilities, adequate capability is required at the metropolitan site to carry out the test program;
2. Requirements are more stringent for aircraft containment to protect the adjacent urban environment; and
3. Since the passenger-operational structure will eventually be required to accept 150-passenger, 150,000-lb (68 000-kg) aircraft, the test structure must meet the same loading requirements because to modify the structure later to carry higher loads would be expensive.

The metropolitan test facility was evaluated for a height of 100 ft (30.5 m), a width of 300 ft (91.4 m), and a length of 2,000 ft (609.6 m). The construction cost is $22 million, exclusive of the costs of land acquisition and arrestment equipment.

An operational facility for STOLcraft operation at the hypothetical metropolitan site expanded to a width of 500 ft (152.4 m) was conceptualized to serve a projected daily demand of 2,300 passengers in 1973, 10,000 in 1984, and 18,000 in 1990. Daily aircraft movements were assumed to be 100 in 1973, 200 in 1984, and 300 in 1990. An

Figure 1. Four-gate operational facility.



isometric view of the operational facility with a flight-deck height of 100 ft is shown in Figure 1.

The single bidirectional runway, expanded from the test phase to a width of 500 ft (152.4 m), is capable in the operational phase of handling 50 operations per peak hour, although the maximum peak-hour demand expected is only 20 operations per hour by 1990. Airside facility requirements are the same as those for the NAFEC site except that in the operational phase an ATC control post is located on top of a 30-ft (9.1-m) tower or at an appropriate height in an adjacent building.

Airside Requirements

Analysis of the passenger demand indicated that a total of 4 gates are required for 1978 and 1984 and 6 or more gates for 1990. The 4 gate areas represent nearly minimum building-size requirements based on operational needs, parked aircraft obstruction criteria, and lateral arrestment requirements. The total area of flight deck and 4 gates is 1,180,000 ft^2 (109 500 m^2). The 1978-84 facility can be expanded either by adding gates on the same side or by developing an apron area and parallel taxiway on the opposite side.

Passenger Facilities

The 4 gates were developed into separate terminal modules each providing ticketing, passenger-holding, baggage-handling, and airline operations. Passenger amenities and other terminal functions are provided in or adjacent to the passageway connecting the gates. Access to STOLcraft is by escalator from the terminal level to the flight deck (to loading bridges in later stages). Access to the terminal area from street and STOLport parking levels is by two 20-passenger elevators in 1978 and 4 in 1984.

At street level, passengers are not separated by arrivals or departures but by mode of transportation. A central island with lobby for elevators, information counters, and baggage checking separates private cars from bus and taxi traffic. STOLport parking for 1984 is on 5 levels between street level and passenger terminal level; 600 cars can park on each level. The passenger terminal requirements including parking are confined as nearly as possible to the area under the STOLcraft apron area.

JOINT-USE POSSIBILITIES

Locating the STOLport in or near the central business district would entail high real estate and construction costs, but the possibilities of joint use and resulting revenues would be high. Joint uses listed in order of their attractiveness for and compatibility with a STOLport are parking, warehousing, light industry, and offices and retail stores. In addition, the STOLport could be placed over a transportation facility such as a highway or railroad.

Probably the most important factor for attracting joint users is the assembly of land into a parcel of sufficient size to accommodate the STOLport. The most promising location for assembling a suitable site is probably in older, central portions of urban areas, which in most cases would also be more attractive to travelers and site users. Moreover, when tracts of this size are assembled, their total area value is often more than the sum of the value of the individual parcels. Thus, one might recover part of the cost of the land and at the same time offer sites at reasonable costs to potential joint users. A methodology was developed to determine available commercial rental space so that a municipality planning for a STOLport can develop cost and revenue based on anticipated demand.

ENVIRONMENTAL IMPACT

Possible beneficial effects are in terms of the total regional transport capability.

1. Additional airport capacity for the metropolitan region can be attained at reduced real estate costs because of the joint uses of an elevated or multilevel facility. In addition, if the facility were combined with an industrial building, the host municipality would lose no tax base.
2. The STOLport can be located close to the urban center and thus significantly reduce access requirements.
3. Noise impact would be minimized because the elevated flight deck would act as a sound reflector when STOLcraft are above the building.
4. A large structure offers opportunities to combine uses and could provide the stimulus for commercial, industrial, or transportation center development.
5. The limited and high-cost expansionability of such a structure will allay fears of future airport expansion.
6. The building height places the operational area above structures and natural barriers that would be obstructions at an at-grade STOLport. This allows more flexibility in site selection.

Potential adverse effects are as follows:

1. The fears of aircraft landing short, veering off the building, or otherwise endangering the surrounding area could cause community apprehension and opposition;
2. Such a large facility will tend to be incompatible with the scale and character of existing nearby development and could cause adverse visual and aesthetic impacts;
3. Noise and vibration transmission through the STOLport building could be a problem to certain joint uses;
4. Aircraft approaching over highways could distract motorists, and pilots could mistake the lighted highway for a runway unless there is proper identification such as colored lights;
5. If the STOLport is located in an urban area, the approach-departure clearance requirements would restrict adjacent building heights; and
6. The elevated STOLport will experience a high percentage of conditions requiring Instrument Flight Rules [e.g., a 200-ft (60.8-m) ceiling at-grade would be a 100-ft (30.4-m) ceiling on a 100-ft-high STOLport].

In the evaluation of a site for an operational STOLport in an urban area, a community would also need information on the extent of noise and types of land use affected, type of land use under approach and departure flight paths, contribution of STOLport operations to air pollution in the area, impact on street congestion and public transportation of vehicles and passengers coming to the site, and impact of construction and operations on the environment.

DESIGN-DEVELOPMENT OF ELEVATED STOLPORT TEST FACILITY

The elevated flight deck, whose dimensions determine generally those of the structure, is essentially flat with slight lateral gradients for drainage. The structure, however, was designed in such a way that superelevation or gradient may be introduced during the course of the test program to determine its efficacy in improving STOL operations. For example, axial gradient might reduce fuel requirements.

Facility Safety

Safety is fundamental to the operational and design requirements of a facility of this type. Facility safety programs have historically focused on postcrash equipment and procedures, the aim of which is damage and injury reduction. Current safety activities distinguish between postcrash procedures and a precrash or accident-avoidance strategy. Design that is aimed at "normal, smooth, and safe" operations falls into this latter strategy. Air traffic control, aids to flight, aerodynamics, and aircraft containment-arrestment fall into the postcrash strategy. Containment-arrestment is a critical element of the elevated STOLport.

Containment-Arrestment

The chief concerns in the development of satisfactory flight-deck containment systems are the terminal activities and populations in the flight-deck area and the modes of containment systems and their effect on equipment and passengers (e.g., brick walls would provide excellent containment but at too high a price). The containment system must have a reasonable cost and operate with minimal damage to equipment and minimal injuries to people. Containment systems, although a fundamental necessity in crash damage reduction, may result in reduced deck-area requirements.

The 2 main elements of containment on the flight deck are longitudinal or end arrestment and lateral or side arrestment. The current state of the art of end arrestment is satisfactory. The FAA requires end-arrestment systems capable of arresting aircraft of 80,000 lb (36 320 kg) gross weight (with growth to 150,000 lb, 68 000 kg) at a maximum landing speed of 65 knots, not to exceed 1.5 g (1.4 m/s^2) within 300 ft (91.4 m), and to operate with a reliability of 3 sigma (2). Longitudinal arrestment devices are satisfactory because the aircraft engages symmetrically: The leading edge of the wings offers an appropriate surface, and the wings act as girders loaded in plane.

The state of the art of lateral arrestment is at present far from satisfactory. The problem of lateral containment is more difficult, for the aircraft is moving away from the centerline at a low angle of incidence, advancing the wing tip and outboard main bogie away from the centerline toward the containment-arrestment assembly first. The engagement of either wing tip or outboard bogie may be expected to aggravate the swerve, requiring a massive arrestment effort and great lateral stopping distance and probably causing both damage and injuries.

In the course of the study, it became clear that inadequate information exists to formulate meaningful criteria concerning containment-arrestment requirements, particularly those concerning lateral arrestment. Some innovative solutions were conceptualized involving curved curbs and rails and bilateral superelevation to redirect aircraft back toward the centerline, but a fuller investigation of this critical area is required. The structure design-development was nonetheless carried out to ensure the structure's integrity to survive arrestment loads on the order of those indicated above.

Aerodynamics

A conventional runway is situated at-grade in the open, and the wind moves across it in a relatively undisturbed mass. The bulk of an elevated deck structure creates a major local perturbation, referred to as a building-induced flow field. In such a flow field, the flow is vertical on the windward building faces, creating large pockets of nonlaminar, turbulent flow along roughly a fourth to a third of the windward portion of the deck, reattaching to the surface, and flowing more or less smoothly downwind from that point (3). Such a situation would be clearly hazardous to takeoff and landing operations. Further, the costs of elevated flight decks tend to limit wind coverage to a single runway; and the constraints of site selection and the problems of parcel assembly in downtown areas tend to indicate not only that there will be only 1 runway but that it will probably not be optimally oriented in relation to the wind rose. Thus, the prevailing wind at a given site may well be a crosswind.

The test structure will initially be open so that the test program can be facilitated and these problems explored. That is, the structure will have no external walls except for some vertical end-corner panels that will be marked to serve as visual cues in landing. The structure is designed so that the entire building can be enclosed for subsequent joint uses. When fully enclosed by paneling, the building can withstand winds as high as 88 mph. The open structure will have less aerodynamic complexity and will provide a better basis for initial study than would an enclosed structure. As experience is developed in taking off from an open elevated facility, wall screen elements can be added selectively and their effects on aerodynamic turbulence evaluated. The structure is also designed to accept various crosswind and turbulence control devices as may be developed from other studies.

Flight Deck

Landing gear loadings were considered paramount among the flight-deck design criteria because, as developed during the course of the study, the deck scheme designs were influenced more by the live loads of the landing gear than by the dead load of the deck. At a 13-ft/sec (3.9 m/s) rate of descent, an impact factor of 200 percent of the gear-imposed loadings was calculated for the runway. The aircraft types assumed were a first-generation 40,000-lb (18 000-kg), 50-passenger aircraft; a near-future 100,000-lb (45 000 kg), 100-passenger aircraft; and a 150,000-lb (68 000-kg), 150-passenger aircraft anticipated for the mature phase of STOL aviation in the 1980s. Building heights of 40, 70, and 100 ft (12.2, 21.3, and 30.4 m) were considered.

EVALUATION OF ALTERNATIVE STRUCTURAL SCHEMES

Preliminary Screening

A preliminary screening of structural schemes appropriate to this application was conducted; novel schemes were also introduced. Twelve potential schemes were developed. An evaluation procedure was used to compare the schemes in terms of the analytically derived unit costs and other factors whose values were based on engineering judgment. Factors, other than direct construction costs, that were taken into consideration included ease of construction, maintainability, life or durability, space use, fire rating, and aesthetics. The 12 preliminary schemes developed were as follows:

1. Orthotropic steel deck with trumpet tower and truss support (has minimum weight deck, shop fabrication, and ease of erection);
2. Orthotropic posttensioned deck with steel tower column support (has considerable weight savings in structural steel);
3. Composite concrete and steel deck with steel column support (uses steel and concrete to best advantage);
4. Lift slab (waffle) deck with steel pipe columns (has lift slab construction);
5. In situ posttensioned concrete deck with concrete columns (has prefabricated formwork and erection from moving platform, better concrete finish, and reusable forms);
6. Prestressed concrete box girders with prestressed concrete columns (has standard, precast, prestressed members and on-site assembly);
7. Waffle slab with trumpet tower and truss support [has precast 20-ft (6.1-m) square units and on-site assembly];
8. Wood panel deck with steel tower columns (has short-span built-up wood deck);
9. Nail-laminated wood and concrete composite deck with steel columns (uses materials for least loading conditions);
10. Glue-laminated wood deck with steel tower columns (is factory glue-laminated and has on-site modular unit assembly);

11. Earth fill (uses readily available and cheap fill materials and standard construction methods); and
12. Cable-suspended structure (is unconventional, exotic scheme and was not examined for that reason).

Recommended Schemes

Two schemes were selected as the most suitable for final analysis and evaluation. Scheme 3, composite concrete and steel deck, and scheme 5, in situ posttensioned concrete deck, were estimated and evaluated for height and aircraft loading variations. Figure 2 shows that if the selection were made on the basis of project cost then the selection process would lead to the lowest height and lightest aircraft. If, however, a 100-ft (30.4-m) height and 100,000-lb (45 000-kg) aircraft weight were used, the difference between schemes 3 and 5 would be $0.75 million, or 4 percent, a nominal difference.

Since both schemes 3 and 5 were adequate in all respects to the requirements of an elevated test facility and their construction costs were essentially the same, the selection had to be based on other considerations. If used at NAFEC, scheme 3 would involve somewhat higher maintenance cost (because of exposed structural steel, which would require periodic painting) than scheme 5, which is an all concrete structure. Scheme 5 was, therefore, recommended for use at NAFEC.

Scheme 3 was selected for the test facility at the metropolitan site because of the expected use of the space below the flight deck. Spans could be designed for 250 ft, thus creating a column-free area. This flexibility in span and column spacing makes scheme 3 particularly appropriate for the varying commerical joint uses below the flight deck of a STOLport.

Scheme 3

Scheme 3 (Fig. 3) has corrugated structural metal plate as formwork for the concrete slab and sheet metal as formwork for concrete joist (or rib) construction. The formwork, prefabricated into panels of modular size for ease of installation, is designed to function as part of the completed structure and therefore would not be removed. The formwork is supported by structural steel trusses that span 50 ft (15.2 m) and are supported by 15-ft (4.5-m) structural steel trusses spanning 100 ft (30.4 m) between columns. The top flange of the smaller truss and the top flange of the large truss are designed as composite concrete and steel members, thus using both materials to their best advantage, i.e., concrete in compression and steel in tension.

Scheme 5

Scheme 5 (Fig. 4), cast-in-place posttensioned concrete, provides the best solution of all the schemes investigated. High-strength concrete of 5,000 lb/in.^{2} (352 kg/cm^2) in compression, reinforced with strands of high-strength steel 270,000 lb/in.^{2} (19 000 kg/cm^2), reduces the quantity of concrete from that required in the usual reinforced concrete construction. Tensioning in 2 directions makes the construction watertight and virtually crack free. The deck and all members remain in compression under all loadings, and the tension cracks that are commonplace in concrete construction do not develop. Large areas can be built without requiring expansion joints, which often create maintenance problems. The structure is designed to be continuous over its supports so that the material savings inherent in this type of load-distribution design can be obtained.

This scheme minimizes the high cost of formwork because the steel formwork can be used repetitively. The formwork, fabricated from steel plates, is supported by steel girders resting on hydraulic jacks. A crane assembly of structural steel moves on rails on wooden tie cribbing. When the tensioning of strands is completed, the deck formwork is removed by lowering by the hydraulic jacks. Then the crane assembly is moved, and the hydraulic jacks lift the deck form to the required position. After the strands are placed in their proper positions, the new area is ready for the placing of

Figure 2. Costs of recommended schemes.

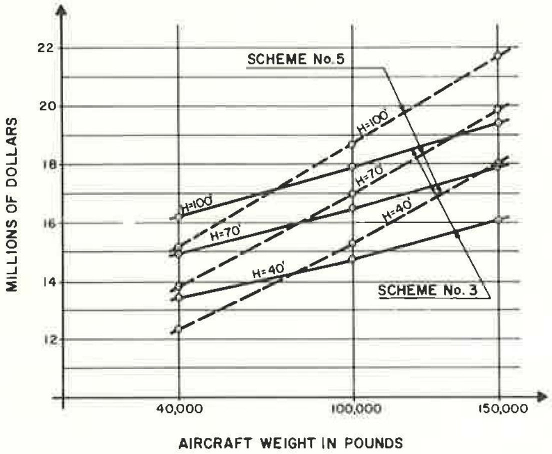


Figure 3. Scheme 3.

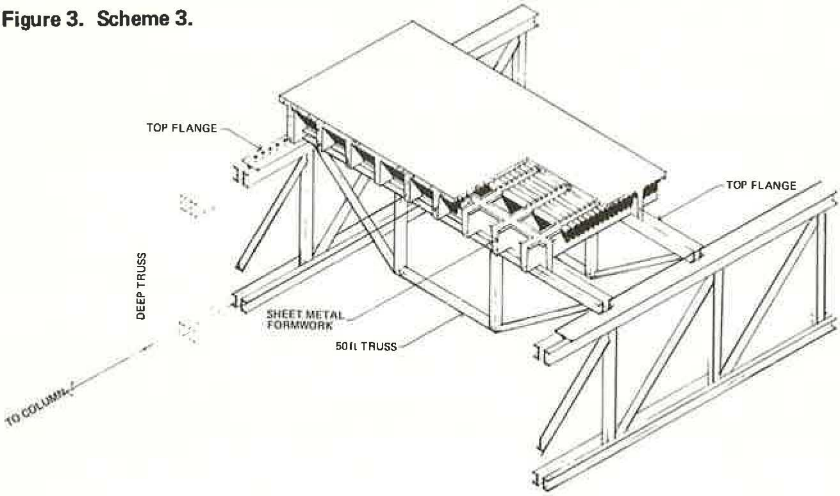
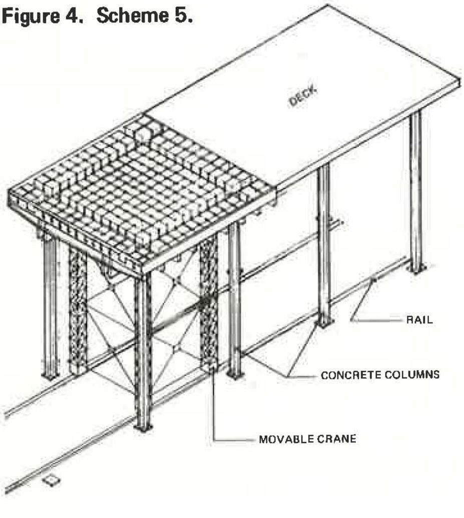


Figure 4. Scheme 5.



concrete. Cast-in-place posttensioning has all of the advantages of precast, prestressed shop production but eliminates transportation, handling, and erection. In addition, the problems of connections between members and smoothing the surface with concrete fill required by precast prestressed construction are eliminated. With cast-in-place post-tensioned concrete construction, the structure is monolithic, which is important because of the large horizontal forces involved in aircraft braking.

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