NASA-LEWIS RESEARCH CENTER

Modification of Altitude Wind Tunnel for Icing and Propulsion Research

Study Part B

MODIFICATION OF ALTITUDE WIND TUNNEL FOR ICING AND PROPULSION RESEARCH STUDY, PART B Final Report (DSMA Engineering Corp.) 129 p

N89-71058

Unclas
00/09 0211478

DSMA Engineering Corporation

24/60

NASA-LEWIS RESEARCH CENTER

CONTRACT NAS3-22933

MODIFICATIONS TO ALTITUDE WIND TUNNEL FOR ICING AND PROPULSION RESEARCH, STUDY PART B

FINAL REPORT

FEBRUARY, 1982

DSMA Engineering Corporation

6220 South Orange Blossom Trail, Plaza Central 1, Suite 186
Orlando, Florida 32809 (305) 851-7442

February 22, 1982

National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

Attention: AWT Project Office, MS 21-4

Subject: Contract NAS 3-22933
'Modification of Altitute Wind Tunnel for Icing and Propulsion Research-Study Part B"
Final Report

The attached material is submitted by DSMA Engineering Corporation in fulfillment of the Statement of Work of the subject Contract.

Submitted By:

H. Wayne Leonard
AWT Project Manager
DSMA Engineering Corporation

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

LIST OF DRAWINGS

INTRODUCTION

This report describes the results of an engineering study conducted for NASA-Lewis Research Center on Modifications to the Altitude Wind Tunnel (AWT) for Icing and Propulsion Research by DSMA Engineering Corporation, Orlando, Florida and DSMA International Inc., Toronto, Canada. The engineering study referred to as study 'Part B' has been carried out under authorization of NASA Contract NAS 3-22933 (Ref. 1).

The scope of work defined in the Statement of Work 3-169855 (Ref. 2) Revised 2/20/81 was discussed in detail with NASA on October 22, 1981 and covers the following areas:

- Fan and Fan Housing. This includes assessment of circuit loss analyses, fan aerodynamics and mechanical conceptual design of variable and fixed pitch fans considering fixed and variable inlet guide vanes.
- Fan Drive Systems - considering fixed and variable speed drives with continuous rating of 30,000 HP with overload capability of 45,000. The drive shaft between the motor and fan is to be considered and also the existing foundations for the main drive motor.
- 20 ft. Test Section Arrangement - having slotted wall configurations suitable for testing at transonic velocities, with various model support systems required for the anticipated models and tests. A model handling concept aimed for high productivity testing and means for quick access to the model in the test section between test runs.
- 45 ft. Test Section - feasible and practical approach for model installation and removal.

All the alternative concepts considered during the early part of the study were discussed in the 50% design review meeting with NASA. At that point NASA provided direction as to which concepts would be developed and finalized to satisfy their anticipated operating requirements. In this meeting we were directed to discontinue further work on the 45 ft. Test Section and concentrate more on the 20 ft. Test Section.

The technical aspects of the study are described in Section II of the report where they are grouped by the major areas into separate sub-sections. Each sub-section describes the concepts considered with more emphasis on the concept selected for preliminary design.

Cost estimates for the equipment chosen in the recommended concepts are described in Section III. This section also describes the basic assumptions used for estimating and the sources of cost data for the major items.

Section IV covers delivery times for the major equipment based on present day situations.

Recommendations and conclusions reached in this study are arranged in Section V.

Drawings and Figures are included in Section VI of the report. Design analyses supporting this study are bound in a separate volume.

SUMMARY

A study has been conducted to develop feasible design concepts for some of the major areas of the Altitude Wind Tunnel to enhance its capabilities and to satisfy the present and future requirements for icing and propulsion testing.

The study covered the fan with its drive system, the 20 ft. high speed test section and, to a lesser extent, the 45 ft. low speed test section.

Before starting the aerodynamic design of the fan, the wind tunnel circuit losses were estimated to determine the fan pressure ratio required to achieve the specified performance of the facility. A single-stage fan design was first assessed and found to be incompatible with the aerodynamic testing requirements. A two-stage design was developed and, after evaluating the constant speed/variable blade pitch option, the final concept was selected that has a variable speed drive system, fixed blade pitch and variable geometry inlet guide vanes and inter-rotor stators.

The mechanical design studies concentrated on the development of a feasible general arrangement of the fan and its main components. Concepts were developed for the fan housing built inside the existing tunnel shell, solid wood construction fan blades, fan rotors and their support and drive system and the variable geometry actuating system.

The fan drive options studied included constant speed systems in the first half of the study and, subsequently, variable-speed systems to complement the final design concept of the fan. The selected system, variable frequency AC synchronous drive, best

satisfies the technical requirements at a reasonable cost. The size of the drive motor will necessitate structural modifications of the existing drive foundations and building.

High speed test section studies were aimed at high productivity model handling and test section access. The final concept, incorporating a lifting platform arrangement, allows installation and removal of models through the test section floor as well as through the roof. The through-the-floor system offers considerable versatility, ease of handling and access to the models for de-icing or modifications between tests. It will accept sting mounted and strut/external balance mounted models; the wing tip mounted models, supported at the test section sidewalls, are installed through the roof.

Limited aerodynamic consideration of the high speed test section has indicated potential problems with testing large models at high transonic speeds in the present test section. Possible approaches to alleviate these problems have been proposed.

The 45 ft. test section requirements were briefly studied to determine means of installation and removal of large models. Feasible approaches were found; however, further development of the design concepts for this test section is being done internally by NASA.

Feasible concepts have been developed for the major areas addressed in the present study. Although careful attention will have to be paid, in the next preliminary engineering design stage, to transform the concepts into satisfactory designs, no serious design problems are expected.

SECTION I
REQUIREMENTS

I REQUIREMENTS

The Lewis Research Center is the NASA field center responsible for research and advanced technology development for aeronautical propulsion systems, space propulsion and power/energy conversion system applications. A key facility that was used to accomplish this mission in the early and middle years of the Center's existence was the Altitude Wind Tunnel (AWT). This wind tunnel was originally constructed in 1942 and even today stands out as one of the major structures at LeRC. It was used intensively for subsonic propulsion research throughout the 1940's and early 1950's and made major contributions to military aircraft programs. With the advent of jet-powered aircraft for flight at higher speeds than the tunnel would permit, new facilities such as the Propulsion Systems Laboratory became more dominant and the AWT eventually fell into disuse. In the 1960's a need arose for large vacuum chambers to support the space program. Consequently, the internal components of the AWT were removed and the shell was used to provide space simulation chambers for environmental tests of launch vehicle upper stages and for space power research. During the 1970's this capability was no longer required and the AWT again was no longer in use. However, during the late 1970's it became apparent that the national needs in aeronautics, as reflected through the research programs of NASA, required a facility like AWT.

The resurgence in interest for icing research is broad and applies to rotorcraft and general aviation, as well as other aircraft types. Rotorcraft and general aviation have some unique problems due to their small size, lower power levels available for anti-icing and de-icing and long flight times at lower altitudes. Currently proposed modifications to the AWT could make a major contribution to NASA's propulsion research programs and, in particular, to the program on Advanced All Weather Helicopters. Performance measurements, aeroelasticity and cooling work on new and advanced propulsion systems would be possible in this unique variable altitude propulsion facility. Work in these areas is needed for NASA programs on advanced turbojets, general aviation, VTOL and rotorcraft. Appropriate modifications will be made such that acoustic characteristics of propulsion systems can also be studied. The rehabilitated AWT would be the only tunnel that could operate at lower speeds with variable altitude and icing capabilities. These capabilities are important for future propulsion system research.

A proposed project in LeRC's future Construction of Facilities budget (FY'85, '86 and '87) calls for modifying the AWT to provide icing and propulsion research capability. As this wind tunnel was constructed in the early 1940's, this special study was conducted to evaluate the existing structure and equipment, and to develop preliminary concepts for new features which enhance the wind tunnel capabilities.

SECTION II
DESCRIPTIVE ANALYSIS

II DESCRIPTIVE ANALYSIS

II.1 Circuit Losses

As part of the present study, DSMA undertook to calculate the losses of the proposed circuit. These losses would be used as input data for design of the fan.

The losses were calculated using an existing DSMA program based on one-dimensional compressible flow with friction and drag. For the calculations, the circuit is broken up into a number of components. The losses are calculated for each component, and the results summed to give the total loss factor. In the present case, 17 components were considered and they can be broadly categorized as follows:

a) Diffusers

For all diffusers, the loss in total pressure was calculated from the static pressure recovery efficiency, η, where:

$$\eta = \frac{(\Delta P_s)\ \text{Actual}}{(\Delta P_s)\ \text{Ideal},\ \Delta P_t = 0}$$

For the four diffusers (test section diffuser, first crossleg, fan tailcone, and fan diffuser), a correlation between η and the blockage at the diffuser inlet was used, where blockage is defined as the area reduction due to the boundary layer displacement thickness.

The correlation between inlet blockage and η was developed from Kenny's treatment (Ref. 4) of the Creare data (Ref. 5). The basic assumptions of the analysis were:

- η is primarily a function of inlet blockage and, to a secondary degree, Reynolds number based on inlet diameter

- η is independent of inlet Mach number
- η is independent of diffuser angle for $3\frac{1}{2}^{o} \leqslant 2\theta \leqslant 6^{o}$
- η is independent of area ratio (since the formulation of η explicitly takes care of that dependence).

The correlation was developed for a reference Reynolds number, based on inlet diameter, of 0.37×10^{6} (for which the bulk of the Creare data was obtained). For other Reynolds numbers, η was corrected using "log law" scaling - no allowance being made for possible roughness effects.

The calculation of inlet blockage for the four diffusers was as follows:

i) Test section diffuser: two factors contribute to the inlet blockage - the boundary layer growth through the contraction and test section, and the plenum re-entry flow.

The boundary layer thickness at diffuser inlet was calculated by estimating the 'equivalent' length of the contraction. The Green-Weeks-Brooman program (Ref. 6) was used to calculate the turbulent boundary layer development over the range of tunnel operating conditions from the downstream end of the settling chamber to the test section exit plane. The equivalent length of the contraction was defined by comparing the displacement thickness at the contraction exit plane with the boundary layer development over a smooth, adiabatic flat plate at the corresponding test section conditions calculated by the method of Winter and Gaudet (Ref. 7). The length of the test section was assumed to be fully effective for boundary layer development.

The contribution of the plenum re-entry flow to the test section diffuser inlet blockage is related to the mass flow and velocity of the plenum flow re-entering the circuit. The displacement thickness at inlet and exit of the slotted wall portion of the test section (walls assumed parallel) was calculated using the Winter and Gaudet method (Ref. 7), ignoring any disturbing influence of the slots. The plenum mass flow is then defined as that required to keep the static pressure constant over the length of the slotted wall section. The ratio of the plenum re-entry flow velocity to the free-stream value was based on previous work. A value of 0.4 was used in the present case. (Note that the limited measurements of Ross and Rohne, (Ref. 8), in NLR HST had indicated a value of 0.5).

ii) First crossleg: it was assumed that at inlet, the flow was fully developed with a 1/7th power law velocity distribution. Based on an average velocity, the inlet blockage was 18%, and this value was used in all calculations.

iii) Fan tailcone: it was assumed that a good deal of reenergization of the boundary layers takes place as the flow passes through the fan and that at inlet to the fan tailcone section, the boundary layers are quite thin. Based on previous fan designs, an inlet blockage value of 3% was used.

iv) Fan diffuser: it was assumed that fully-developed turbulent flow was achieved at the end of the fan tailcone, that the boundary layer growth was such that the displacement thickness along the outer shell was half that along the strongly converging tailcone and that the displacement thicknesses were 1/8th the corresponding boundary layer thicknesses. However, for calculating the influence of blockage on the fan diffuser 'η', only that blockage component resulting from the outer shell displacement thickness was used, it being argued that the central low total pressure region, since it does not directly influence wall friction, would not have a major influence on static pressure recovery (no systematic experimental data are available to verify this point).

b) Test Section: For the test section loss, the mean skin friction coefficient was calculated by the method of Winter and Gaudet (Ref. 7) using the equivalent lengths of the contraction described above.

c) Model/Strut

It is known that, particularly at higher Mach numbers, the model and strut can contribute significantly to the total circuit loss factor,and allowance was made for these components in the present analyses. For the model, a value of $\frac{C_D S}{A} = 0.02$ was used for all Mach numbers. Model load estimates were used to develop a preliminary geometry for the strut/sting combination. In the present case, only a simple strut was considered. In the future, the full range of models to be tested with the associated model support system should be analysed. The strut/sting loss was considered to be made up of three components:

- Friction drag of strut and sting - the data on section profile drag at low speeds given in Duncan, Thom, and Young (Ref.9) were used to define a correlation for mean skin friction coefficient based on strut chord Reynolds number and thickness/chord ratio.

- Wave drag of sting and sting boss - data given in Hoerner (Ref. 10) was used to calculate the wave drag coefficient for this component - a relatively small contribution. For Mach numbers of 0.9 or less, this coefficient is zero,and this contribution was neglected in the present case.

- Wave drag of strut - for strut wave drag, the strut was considered as an equivalent,double wedge airfoil, and the wave drag coefficient was calculated from simple-equation fits to Hoerner's correlation of transonic similarity data.

It was assumed that there was no interaction between these drag components and that they were simply additive.

d) Corners

As suggested by NASA-Lewis, a local loss factor of 0.13 was used for the turning vanes in each corner. Based on existing data, this is a reasonable value. As provision for a safety screen in corner 2, an additional loss factor of 0.1 was applied in this corner.

e) Heat Exchanger

As suggested by NASA-Lewis, a local loss factor of 2.5 was used for this component,and it was assumed it was mounted in the second crossleg. It is considered that this is a critical circuit component,from the points of view of both losses and flow quality, and must be studied in some detail during some later stage of the design program.

f) Flow Conditioning Devices

Although the flow quality requirements for the facility have not been defined, it was considered that some flow conditioning would be required,and allowance was made in the present calculations. At the end of the fan tailcone and in the settling chamber, local loss factors of 1.0 and 3.0,respectively,were applied to account for flow conditioning upstream of the two test sections. Based on a preliminary analysis, it appears that a turbulence intensity better than 0.5% could be achieved in the 20' test section by having a honeycomb/screen combination with a total local loss factor of 3.0 mounted in the settling chamber. This is dependent on the heat exchanger configuration, and no allowance was made for an icing spray rig.

g) Other Components

All other circuit components are constant area sections, and the losses were calculated from a correlation of standard friction factor-diameter Reynolds number data.

The geometry of the circuit was taken from an airline of the original AWT circuit supplied by NASA-Lewis. Some slight changes were made in the fan region as the fan design progressed.

The loss calculations were done for four tunnel operating points, three at approximately 25,000 HP (including the design point) and one at low power (approximately 1,200 HP). The actual conditions were:

1. Design point, M = 0.8, h = 47,000'
2. M = 0.9, h = 55,000'
3. M = 0.38, sea level
4. M = 0.2, h = 30,000'

For the altitude cases, the static pressure and temperature in the small test section were taken from standard tables of atmospheric conditions. It should be noted that part of the upper left portion of the facility operating envelope proposed by NASA-Lewis (Fig. 2 in Ref. 2) will not be achievable if the minimum total temperature downstream of the heat exchanger is -20^{0}F since, for lower Mach numbers at higher altitudes, it will be impossible to achieve the correct test section static temperature.

The results of the loss calculations are given in Figures 1 and 2 as the variation of total circuit loss factor with small test section Mach number and variation of fan pressure ratio with mass flow, respectively. Detailed results of the loss calculations for the four cases are given in Table 1. Fig. 1 shows that the circuit loss factor decreases somewhat with increasing Mach number in the low Mach number range and that it begins to increase sharply as the transonic regime is approached. These results, and the fan operating curve given in Fig. 2, are consistent with data for other wind tunnels operating in the same Mach number range.

The main result of the present calculations is that a drive power of 25,000 HP is required to achieve the design point of M = 0.8 at 47,000' with a small model in the test section. This power would increase for the large models proposed by NASA-Lewis, but no estimates were made for this case.

II.2 Fan and Housing

a) Fan Aerodynamic Design

As part of the present study, a preliminary analysis was made of the aerodynamics of the fan. The results of this analysis, indicating the options which were examined and their various advantages and disadvantages, are summarized below.

Since consideration of the fan was begun at an early stage of the overall study, the required performance was derived from the circuit-loss estimates supplied by NASA-Lewis. These give a fan design pressure ratio of about 1.2 and a maximum pressure ratio of about 1.3. Subsequent analysis by DSMA has indicated that the losses may be somewhat lower, but the differences are not large enough to affect the conclusions regarding the fan. The differences correspond roughly to the margins of safety which would have been used in any case (to allow for the possible addition of flow-quality control devices, for example).

In general, the preliminary aerodynamic analysis consists of two main steps. A given option is first examined by hand calculations made for the hub, the mean radius and the tip regions. These calculations indicate the relative Mach numbers which can be expected and the blade loadings which will occur for reasonable values of solidity. If a particular option seems sufficiently promising, the hand calculations are confirmed by running the DSMA fan design-point program. This program performs a full, compressible radial-equilibrium analysis of the flow after each blade row, takes into account the total-pressure losses through the rows and includes the effect of the flow non-uniformity at the fan inlet. The results produced by this program have been found to be reliable previously when compared with the results obtained by the more sophisticated streamline-curvature program which is used at DSMA for predicting off-design fan performance.

i) Single-Stage Fan

The possibility of using a single-stage fan was examined first, and essentially this option does not appear to be feasible. The maximum performance which can be obtained, without putting the fan well into the transonic class, corresponds roughly to the intended design point. Even under these conditions, the relative Mach numbers at the rotor will be on the order of 0.85 and will therefore lead to significant noise and other flow quality problems. Since the critical region for blade aerodynamic loading turned out to be the rotor tip (with diffusion factors of 0.4 or slightly higher even for a very high blade solidity of 1.0),there does not appear to be much scope for reducing the relative Mach numbers. For example, inlet guide vanes could be used to reduce the relative velocities,but this would also result in an increase in the aerodynamic loading.

As well as necessitating a reduction in the tunnel Mach number performance, a single-stage fan would have serious impact on the overall circuit aerodynamics. Even to obtain the performance mentioned above, it was necessary to reduce the cross-sectional area at the fan to essentially the test section area. As a result, a very large amount of diffusion would have to be done in the relatively short length between the fan outlet and the inlet to the large test section. In fact, a preliminary analysis has shown that it is doubtful whether stable, attached flow can be maintained in the fan diffuser even with the use of vortex generators. This second large area-ratio diffuser would also significantly increase the circuit losses.

To summarize, the use of a single-stage fan would necessitate a reduction in the tunnel Mach number performance, would create noise problems and would make the feasibility of the large test section doubtful.

It was concluded that this option did not merit further considerations. This decision was discussed with NASA-Lewis,and they concurred.

ii) Two-Stage Fan

In general, a two-stage fan would eliminate or reduce most of the problems noted above. In the first place, it would result in significant improvements to the geometry in the fan region. It was found that acceptable blade loadings could be obtained with a fan area about 1.8 times the test section area. This should eliminate all problems with the fan diffuser. Furthermore, it was found useful to reduce the fan speed and to increase the tip diameter to the available 31 ft. The increase in tip diameter has the advantage of raising the hub-to-tip ratio for a given cross-sectional area, which improves the blade loadings by making them more uniform. Using the full available diameter would also simplify the design and manufacture of wall inserts for the fan tip region (fan housing).

In terms of the fan aerodynamics, the two-stage option also appears very satisfactory. With reasonable solidities (say about 0.75 at the rotor tip) the aerodynamic loading is moderate at the design point,and there appears to be no doubt that the maximum pressure ratio can be obtained. This applies whether variable pitch or variable speed is selected. The maximum relative Mach numbers will still be somewhat high (at about 0.75) but are more tolerable. Again, this applies to both the variable pitch and the variable speed fans although the design speeds will be slightly different.

For the variable speed fan the design speed will be about 420 rpm, with slightly over 500 rpm being required at peak pressure ratio. Since variable pitch fans tend to have less surge margin, a somewhat higher design speed would be used here. About 480 rpm appears to be satisfactory.

The differences between fixed pitch/variable speed and variable pitch/fixed speed fans were assessed, and the advantages and disadvantages between them are discussed below. It should first be made clear that the use of variable pitch will have a significant and detrimental effect on the flow quality in the tunnel. Swirl in the fan outlet flow would not be the major problem. Although the swirl in the rotor outflow will vary over a considerable range, by using high-solidity stators it should be possible to largely remove this for all operating conditions. Any residual swirl could be removed by a flow straightener near the outlet of the fan diffuser. The main flow-quality problem will come from the velocity (or total pressure) non-uniformity which will be present in the fan outflow at all operating conditions other than the design point. This non-uniformity comes about,because away from the design pitch setting, large portions of the rotor blade will be operating off-design. For example, preliminary calculations for this fan show that to increase the pressure ratio from the design value to the peak value,we would need to change the blade pitch at the hub by about 15^{0} but by only about 3^{0} at the tip. Obviously, in order to obtain the required mass-averaged total pressure rise, some intermediate pitch setting would actually be used, but the result will be that much of the blade will be producing either more or less than the desired pressure rise. Consequently, the downstream flow will have a non-uniform velocity distribution.

This non-uniformity will be further amplified by the fan diffuser so that the large test section is likely to see a highly non-uniform flow under most conditions. There may be some scope for improving velocity uniformity by promoting large-scale mixing downstream of the fan, but this clearly presents a greater problem than removing swirl. By contrast, a variable speed fan is able to maintain good flow uniformity over a wide range of operating conditions.

It should be noted that although the velocity non-uniformity will mainly be a problem for the large test section, it may also be detectable in the main test section because of the relatively modest contraction ratio in this tunnel.

It will be evident from the above discussion that a variable speed fan is preferable from the aerodynamic point of view. However, it has been pointed out that a variable speed drive cannot deliver its rated power at part speed whereas the tunnel performance requirements call for constant power to be available over a wide range (roughly from half speed to full speed for the variable speed fan). Thus, if variable speed were used, either the drive would have to be over-sized or some reduction in maximum available Mach number at the lower 'altitudes' would have to be accepted. Similar compromises would almost certainly have to be made for the constant speed, variable pitch configuration. The reason for this is that the efficiency for a variable pitch fan falls off quickly away from the design point. Based on the characteristics of a large, variable pitch fan used by DSMA on a previous project, it is estimated that the efficiency will drop from about 87% to about 65% over the range of Mach numbers 0.8 to 0.43 (the range for which AWT is to be capable of constant 'air power'). Thus, if a shaft power of 30,000 HP is needed to supply the 'air power' at

M = 0.8, about 40,000 HP will be necessary to obtain the same 'air power' at M = 0.43. It follows that the drive will again have to be over-sized, or somewhat reduced Mach number performance will have to be accepted.

Estimates were made of the maximum power boundary for the two cases, and these are given in Table 2. The main difference is at the sea level condition where the achievable Mach number with the variable speed drive is lower than that with the variable pitch fan. These results are based on the assumptions that the aerodynamic efficiency of the variable pitch fan at the sea level condition is 0.65, and that the shaft power from the variable speed drive varied linearly with speed up to that corresponding to the design point.

Obviously, other considerations such as cost will have to be taken into account when making the choice between variable pitch and variable speed. At this point it is simply noted that, firstly, there must be a strong preference for variable speed on aerodynamic grounds, and, secondly, the performance advantage of constant speed is not as great as it appears at first glance.

The above considerations were discussed with NASA-Lewis, and it was agreed that design would proceed on the basis of a 31 foot diameter, two stage, fixed pitch/variable speed fan. DSMA undertook to assess the performance gains to be achieved with variable inlet and inter-rotor guide vanes for this fan.

iii) Variable Guide Vanes and Stators

At this stage it is difficult to estimate the precise amount of variability which will be required or the benefit in terms of improved efficiency which will result. This can be done only once a full fan map has been predicted,and this is beyond the scope of the present study. The aerodynamic design is therefore based largely on our previous experience with another large fan employing variable inlet guide vanes. As a result, the configuration is somewhat tentative, but is regarded as a valid basis for developing the general mechanical design concepts and for assessing the cost implications.

Based on the earlier experience, it is estimated that 30° of IGV movement should be ample. The same range of travel is also to be provided for the stators although the movement of the two blade rows will not be ganged. To maintain reasonable aerodynamic loading, there should be 12 vanes of 1.25 m. chord length (or some other combination which produces the same solidity). Since 30° of incidence cannot be tolerated, the turning will be obtained by using variable flaps. These will occupy about 35% of the chord length. The fact that a large portion of the IGV's will be fixed will allow them to double as the front support struts for the fan.

The preliminary aerodynamic investigation of the variable IGV's has revealed that in the present application,the benefits may not be as great as at first anticipated. The reasons for this will be explained with reference to the schematic fan map shown in Fig. 3. This figure shows the fan operating curve (similar to Fig. 2) and two fan maps - one for IGV's undeflected (solid lines) and the other for the IGV's deflected (dotted lines) to increase the rotor loading. Each map consists of the surge line, region of maximum efficiency, and three constant speed lines.

To improve the efficiency at part speed, the IGV's would be used to shift the fan map to the right. This would be accomplished by turning the flow such that the rotor loading is increased. This results in the rotor design incidence, and therefore maximum efficiency, being obtained at a higher mass flow rate. Referring to the map, it can be seen that while this does achieve the desired increase in efficiency at the part-speed operating point, that same point will also be obtained at a lower fan RPM (at N_3 say, compared with a speed between N_2 and N_3 for the design-point fan map). Thus, while the higher efficiency means that a larger fraction of the shaft power is obtained as air power, the reduction in RPM will also mean a reduction in the available shaft power. The net result could well be a reduction in the air power, which is the reverse of the effect intended.

Continuing this argument further, it would seem that if variable IGV's were incorporated, they might be used in different ways according to which test section is in use:

1. Small (Main) Test Section

   This test section will be more tolerant to fan-outlet flow non-uniformity, and the main consideration will be to maximize air power. In this case it might well be best to use the IGV's to shift the map into a region of lower efficiency in order to raise the required RPM and, therefore, to increase the available shaft power.

2. Large Test Section

   Here the main consideration is likely to be flow quality. Changes in air power result in only small variations in the air velocity because of the narrow total range. In this case, therefore, the IGV's might be used to improve efficiency and thus fan-outlet flow uniformity. However, since we expect the variable-speed fan to be able to maintain reasonably good efficiency over a wide range of operating points anyway, the benefits may not be very great.

It should be pointed out that use of variable IGV's has safety implications which will complicate the design of the fan control system.

Referring to the fan map, it can be seen that with the IGV's set for part-speed running, an increase in fan RPM could result in the surge line being crossed at less than the full available fan RPM. Since this is a reasonably high performance fan which is likely to have a fairly abrupt and severe stall, stall should be avoided under all conditions. There will therefore have to be a failsafe interlock between IGV/stator position and fan speed.

In effect, there will have to be a variable fan speed limit which is a function of IGV/stator position.

An emergency back-up system (with its own power supply) should probably also be provided to drive the IGV's and stators to their "safe" position in the event of a controls or other failure.

At this stage it appears difficult to conclude whether much is to be gained by incorporating variable IGV's and stators. The net benefits could well be minimal. More firm conclusions will not be possible until a preliminary fan design has been made and the corresponding fan map has been generated.

For the purposes of the present study, it seems reasonable to assume that variable IGV's/stators will be used to develop the preliminary mechanical design concepts and to assess the cost implications. During the preliminary engineering, a fuller assessment can then be made, and the benefits can be weighed against the costs more definitively. At that point it could conceivably be decided to abandon variability.

iv) Maximum Power

Preliminary estimates of the maximum power boundaries for a variable speed drive with power levels of 25,000, 30,000 and 45,000 HP were made,and the results are summarized in Table 3. These results apply only for small models and are based on an extrapolation of the circuit loss curve (Fig. 1) which is somewhat uncertain as Mach 1. is approached. Use of the variable IGV's would tend to give higher Mach numbers at the sea level operating points.

b) Fan Mechanical Design

The purpose of the mechanical design studies of the fan was to develop feasible design concepts for the fan arrangement and its major components. Studies were based on the two-stage design resulting from the aerodynamic analysis.

The initial work was done for the variable blade pitch/constant speed design,and the resulting layouts are shown on E44527 and E44528. Differences between this concept and the final concept (fixed pitch, variable speed and variable inlet guide vanes and first stators) will be noted in the discussion.

Major areas of the AWT fan considered in this study were the fan housing, blades, rotor, shaft and bearings, variable geometry systems and the fan drive train components.

i) Fan Housing

The size of the fan is essentially dictated by the existing shell size and from the tunnel circuit considerations. It was concluded that the maximum fan diameter would minimize fan diffuser problems. From these considerations and evaluations of the shell structural aspects, it was concluded that the fan diameter be 31 feet.

During the early part of the study it appeared to be quite obvious that the approach of building the fan housing in the existing shell is much more attractive than cutting out a section of this shell and providing a new section specifically designed as a fan housing.

Where necessary the tunnel shell in the fan area can be reinforced with circumferential stiffening rings to provide better support for the fan nacelle. The inside contour of the fan housing can be formed by an inner shell attached to the existing pressure shell. This inner fairing does not have to be designed for the pressure loads.

The fan nacelle consisting of the nosecone, stator vane rings and the tailcone will also provide means of supporting the fan rotor assembly. It is connected to the outer shell of the fan housing by a number of support members. For the nosecone and upstream bearing assembly, these support members are the fixed sections of the variable inlet guide vanes. The first stage stator vane ring assembly is similarly supported by the fixed sections of the variable geometry stators. The tailcone and the downstream (main) bearing assembly are connected to the outer shell by the second stage fixed stator vanes. In addition, support struts will be provided at the downstream end of the tailcone.

Considering briefly the possible erection sequences, it was determined that structural components can be brought inside the tunnel shell through the large opening used to install the models into the low speed 45 ft. test section. Overall, although the erection procedures will require careful attention in design, they are unlikely to cause any serious problems.

ii) Fan Blades

Feasibility of the fan blades was established using the following criteria:

- satisfactory strength and vibration performance
- material suitable for the AWT (icing) environment
- proven technology for fabrication

At first, quick comparative analyses were made of the two rotor blade concepts: solid laminated wood and stainless sheet steel fabricated construction.

The sheet steel construction was found to be heavier, more complicated and probably more difficult to procure as no specialist suppliers of such blades are known. Wooden blade was chosen for development of conceptual design.

Wooden blade concept is suitable for this application, and the fabrication technology is very well developed. The construction typically consists of the airfoil laminated from Sitka spruce,and impregnated wood sections are gradually spliced in toward the root section. The root is completely made of impregnated wood. The blade is covered with fibreglas,and the leading edge is normally protected by a metal strip to minimize damage by foreign objects.

In this case, special precautions will be necessary to prevent accumulation of ice. These may include a heating system at the leading edge. In the cost estimates, cost of such a system has not been included.

Several designs exist for attachment of the wooden blades to the fan rotor. DSMA has developed and successfully used an attachment consisting of a ferrule fastened to the blade root section. The ferrule is inserted into a socket in the rotor and fastened to it by means of a fixing ring and a number of bolts. This design is shown on drawings E44528 and R44530.

A more detailed analysis of the wooden blade indicated the root centrifugal stress of approximately 1500 psi. This stress level is considered satisfactory since the allowable strength of impregnated wood is at least 6,000 psi.

Bending stress level was approximately 900 psi. During the subsequent design stage, bending stress on the fixed speed fan can be substantially reduced by tilting the blade. To a lesser degree, this can be achieved on the variable speed design. However, the combined stress of 2400 psi for the untilted blade is below the allowable level, a satisfactory situation for this stage of design.

A preliminary vibration analysis gave the results shown on the interference diagram, Figure 4. The diagram was used to determine the number of support struts upstream of the the first rotor stage.

Nine (9) would be used in the fixed speed design to achieve high margins of safety on all the lower modes of vibration at the operating speed. In the variable speed design, resonances within the operating speed range cannot be avoided; however, the designer should seek to minimize their number or at least to shift them to lower speed. Seven (7) support struts were selected in this case, thereby removing the first torsional resonance from the operating range.

Note that the safety margin to this resonance at the top speed is lower than desirable,and a change of blade geometry on the final fan configuration may be required to improve the situation.

The question of ice damage to the blades was briefly considered and discussed with the NASA AWT Project Group. Wooden blades are fairly damage tolerant,and minor repairs are simple. Damage will likely be concentrated at the blade tips. The blade tip clearance should be minimized to achieve high efficiency,thereby increasing the likelihood of damage by large pieces of ice. This could be alleviated by using breakaway tips on the blades. However, it is felt that their replacement may be so frequent as to become a nuisance.

NASA suggested that,as an alternative, a few circumferential cavities resembling a labyrinth seal could be made in the fan housing at the locations of blades. Besides acting as tip seals, they would also collect the ice,this way preventing damage to the blades.

It was concluded that a detail evaluation of the above methods should be made in the next design stage.

iii) Fan Rotor

A rotor for this size of fan will typically have two major components - a forged hub fastened to the rotor shaft and a disc weldment bolted to the hub. In a standard DSMA design, fan blades are attached to the rotor hub through blade carrier assemblies so that the hub must support the blade pull loads in addition to its own centrifugal loads. Blade bending loads are resolved between the hub and the outer part of the rotor disc where the blade carriers are located in sliding type bearings.

In this study, basic design arrangements of the rotor were developed for the variable pitch and fixed pitch fan concept.

The rotor hub diameter of the variable pitch fan (see drawing E44528) was dictated by the size of the blade thrust bearing. This bearing turned out to be a critical component of the blade attachment system. To support an estimated blade pull of 330 Kips, an antifriction bearing (necessary to obtain low torque on the pitch mechanism) with an outside diameter of 11" was necessary. This resulted in the rotor hub having a diameter of 109 inches.

In the fixed pitch fan, the bearings are no longer required, and the rotor hub diameter could be reduced to 84 inches. This layout is shown on drawing E 44530.

Average hoop stress levels combining the rotating ring with blade pull stresses for both fans were estimated in the range of 20 - 30 Ksi which is satisfactory. It is expected that these stresses could be reduced, if necessary, by optimization of the blade attachment and the shape of the hub.

iv) Fan Rotor Support and Drive System

The assembly of bladed rotors and the rotorshaft is supported by the bearings that transmit the loads from these rotating components to the fan housing. The rotor shaft is also connected to the drive shaft that supplies the motive power to the fan. Therefore, a suitable integrated system must be developed that includes the above components and can carry all the loads imposed on it (within the fan operating range) without excessive vibrations. At the same time, the system must allow any necessary differential thermal movement between its components.

After an analysis of the requirements and several schemes, a basic arrangement of the system was developed for the variable pitch fan concept. The fan rotor and shaft assembly is straddled by two support bearings. The downstream main bearing fixes the rotor location and is designed to support radial and axial (thrust) loads. The upstream bearing supports only radial loads and allows axial float.

The rotor shaft is connected to a fan drive shaft by a flexible coupling. The fan driveshaft is supported by a radial bearing at the point where it penetrates the tunnel shell at the second corner. At this point of penetration, a seal is also necessary. The end of the drive-shaft is then connected to the drive motor shaft by a so-called spacer coupling. This coupling is designed to accommodate all the axial (approx. 2") and transverse (approx. 1") differential thermal movements between the fan and the motor and consists of two gear couplings separated by a tubular spacer.

The differential movements occur during the tunnel operation, and axial thrust will be generated as a result of friction in the couplings. This load must be taken into account in the design of the main fan bearing and drive motor thrust bearing.

Based on this arrangement, the individual components were sized and design layouts developed. The layouts were subsequently used also for the fixed pitch fan, drawing E44529.

The two shafts are tubular with solid ends. The diameters of the ends were calculated to transmit the maximum torque while the dimensions of the tubular portions of the shaft were selected to give a minimum of 30% margin on the rigid bearing first critical speed for lateral vibrations.

All the bearings are of the rolling element type. The main bearing is a double row,taper roller bearing while the other two are self-aligning,spherical roller bearings. Bearing life estimates were made under the worst case load conditions and indicate 10,000 hours for all the bearings can be achieved. An automatic oil lubrication system will be used for the bearing lubrication. An emergency back-up system will also be required and will be activated automatically in the event of failure of the main system.

The couplings - gear-type flexible couplings - were sized in co-operation with a large coupling manufacturer.

v) Variable Geometry Systems

Basic design concepts were developed for the variable blade pitch system, and for the variable inlet guide vanes.

The variable blade pitch system, the same for each of the two rotor stages, is shown on drawing E44528. Its operation can be described as follows:

The blade pitch is adjusted by rotating the blade carrier which is supported by two bearings - a thrust bearing which was mentioned previously, and a radial bearing which allows axial float. The blade carrier is driven by a lever and linkage system connected to a translating ring. The ring is guided within the fan rotor hub and is actuated by several struts which pass through slots in the fan rotor shaft and are connected to a stationary actuator inside the fan nacelle. A hydraulic servo or ball screw actuator system could be used.

The actuating system for the variable inlet guide vanes and for the first stage stator vanes will be similar, and its concept is shown on drawing E44530. The systems will be located inside the fan nacelle and will drive the trailing edge flaps.

Each hinged flap is driven by a lever linkage connected to a ring which rotates about the fan axis. The ring is supported on several rollers and actuated most likely by a hydraulic servosystem.

Design development of the actuating system for the inlet guide vanes and stators is not expected to create any difficulties.

II.3 Fan Drive

Initial review of the new fan drive requirements, prior to the finalization of the fan design concepts, included investigations of both variable speed and fixed speed drives. While the final design of the fan dictates the requirement for variable speed, both drive types have been compared for the purpose of this study.

Costs presented have been based on a drive size of 30,000 HP at 480 RPM with comparisons for increased ratings up to 45,000 HP. In arriving at costs, estimates have been received from two large U.S.A. manufacturers and one large European manufacturer. On the basis of estimates received and qualifications placed on such estimates by these suppliers, the level of accuracy can be categorized in the range of ±20%.

Variables compared for the drive types considered include:

- initial equipment costs
- installation costs
- operating efficiency
- performance capabilities

a) Fixed Speed Drive

Two systems have been considered:

i) a wound rotor AC motor with a liquid rheostat used for a 'soft' start

ii) a synchronous AC motor with variable frequency 'soft' start equipment.

In sizing the soft start equipment,a capacity of 10% of the maximum load has been assumed. It was assumed that the variable pitch fan could be pitched to a zero load angle,and the only power required would be to accelerate the mass of the rotating parts.

In the synchronous motor case, the operating speed would be 514 RPM (synchronous speed for a 14-pole machine). While this is higher than the final fan design maximum speed, the machine size is the closest possible for pricing comparisons.

Motor costs for the two systems are shown in Table 5, while total drive system (motor, starting and control equipment) costs are shown in Table 4. Installation costs would be approximately 30% of the initial equipment costs.

Comparing costs, the synchronous motor system, even with its starting network (switched out after line synchronization), is considerably cheaper.

Efficiency of these drive systems will be in the range of 85-90%, with the synchronous motor being approximately 5% more efficient than the wound rotor motor with the liquid rheostat. This assumes full speed operation for the wound rotor machine.

b) Variable Speed Drive

During the study, the analysis of tunnel performance requirements has shown the preference for a fixed pitch, variable speed fan with adjustable inlet guide vanes. The additional investment for a variable speed drive compensates for the simpler fan, without variable pitch mechanisms.

The drive systems considered include:

i) wound rotor AC motor with liquid rheostat

ii) wound rotor AC motor with a static slip energy recovery system

iii) AC synchronous motor with variable frequency speed control

Initial equipment costs, installation and operating costs are shown in Tables 5 through 11. Efficiencies of the three drive systems are shown in Figure 5, and a summary of performances is shown in Table 12.

The differences in operating costs are attributed to the differences in the energy losses related to the operating principles of the different drive systems. While the same duty cycle has been assumed for all drive systems, the duty cycle considered is an assumed duty cycle, based on the best present estimates of tunnel usage. Any changes in operating loads or times will change these figures accordingly. The cost of power used in arriving at the operating costs has been taken at 4¢/kwh, consistent with present day rates paid at NASA Lewis ReC. This rate must be appropriately escalated when considering future operating costs.

When comparing equipment and lost energy costs, it is apparent that the energy savings associated with the synchronous motor drive system will eventually pay for the difference between it and the cheaper wound rotor motor, liquid rheostat system. A direct comparison of the numbers shown may not be a fair comparison, however, since the cost of financing the larger initial investment for the synchronous motor system has not been considered.

When reviewing performances of the three drive systems, apart from efficiencies (as shown in Table 12), the synchronous motor with with variable frequency speed control offers the highest level of performance. The wound rotor motor with liquid rheostat has the poorest overall performance with a controllable speed range of only 3:1, while the wound rotor motor with slip power recovery can be relegated to the medium performance class. However, it is more expensive than the synchronous motor system.

c) Fan Drive Motor Size and Installation

Preliminary estimates of the size of the fan drive motor were obtained from the manufacturers contacted. The motor has been indicated on E44529. From a brief review of the existing drive building and motor support base,it has been concluded that it is not feasible to use the existing upper part of the building with the present support base for installation of the motor.

The building will have to be partially demolished and the foundations with the support base enlarged. Then, the outer walls and roof must be rebuilt. The extent of building modifications will be determined in the preliminary design phase when the motor size and weight can be determined with a greater degree of reliability.

The motor size shown on E44529 is for a single 45,000 HP motor. A 2-motor tandem arrangement, coupling two 22,500 HP motors in series, was considered as a possible alternative to alleviate the space problem. While the height and width of such an arrangement are reduced by approximately 20%, the overall length increases by approximately 35%. This arrangement would still require extensive building and foundation modifications and would require additional alignment precautions. In addition, the cost of such an arrangement would be approximately 10% higher than for the single motor drive. Hence, there appears to be no justification for further consideration of a tandem motor arrangement.

d) Conclusions and Summary Comments

On the basis of the analysis made, the preferred drive system is the synchronous motor with a variable frequency speed control. An overall block diagram of this system is shown in Figure 6.

Figure 6 also shows the division between the equipment covered in the above pricing and additional required power supply equipment. In addition, power factor and harmonic compensation requirements must be assessed, taking into account the complete structure and capacity of the power distribution system.

II.4 20-Foot Test Section

The high speed, 20 ft. test section will be the principal test section of the rehabilitated AWT. Its operating envelope covers a wide range of speeds, from almost zero to transonic in excess of Mach 0.9, and simulated altitudes up to 55,000 feet. The predicted performance boundary is given in Table 3.

Icing test programs will constitute a large portion of the testing time; the rest will be mostly propulsion and general aerodynamic and acoustic tests. All these tests will involve many different types of models, from single engines to complete airframes or sections thereof.

a) Technical Requirements

The technical requirements for the test section were discussed with NASA at the first project meeting on the 22nd of October 1981 and are summarized below.

(i) The test section geometry should be modified to a slotted wall configuration, to minimize wall interference with models during transonic testing.

(ii) To accomodate different models and various anticipated tests, three model supports would be required:

- sidewall model support for large models spanning the test section. ($M \leq 0.9$)
- strut model support with turntable for full or half models supported from an external balance located underneath the test section. ($M \leq 0.3$)
- sting model support for testing of smaller models with internal balances. ($M \leq 0.9$)

(iii) High productivity of testing will be one of the most important overall requirements for the rehabilitated facility. This would require means for fast model exchanges and access to models between test runs as well as fast data acquisition. Intention is to achieve this with a minimum of manpower and energy consumption.

It was agreed that this study would concentrate on concepts of model handling and quick accessibility to satisfy the above requirements.

b) General Considerations

At the outset of the study, the NASA requirements were reviewed and discussed to get as complete an understanding as possible of what were the important aspects of the tunnel operation. During this review, some basic ideas were considered as to their feasibility, with an aim to narrowing down the available options.

i) Isolation of Test Section

After a typical test, the wind tunnel remains evacuated and cooled down to a low temperature. Under these conditions, it is not possible to enter the test section, nor to withdraw the model. Therefore, thought was given to isolating the test section by two gate valves. Then the test section could be brought up to normal atmospheric conditions,with the rest of the tunnel remaining at altitude conditions. It was determined that suitable valves of the size required to seal the 20 ft. circular cross-section would be very expensive. When open, the gate valves would create large gaps in the airflow surface that would be difficult to close. The effect of such gaps at the outlet of the contraction would be a significant deterioration of the flow quality in the test section.

Furthermore, it would take about the same time to open or close the valves as the maximum time necessary to evacuate the tunnel by the existing suction system (about 6 minutes). Therefore, no time would be saved using this approach.

As a result of the above, this concept was rejected. The tunnel would be brought to normal atmospheric pressure whenever access to the model was necessary. However, it was decided that isolating curtains should be provided at each end of the test section to minimize energy losses when the cold tunnel is exposed to the outside air by opening the test section.

Similarly, a brief consideration was given to a suggestion by NASA to move the model with its support to an isolated "airlock" chamber above or on the side of the test section. An airlock on the top of the test section was considered and discarded because of the extreme heights to which the model and support would have to be raised, potential complexity and difficulty of handling the large models. The airlock on the side of the test section would force large modifications of the existing building to be made.

This left one other area available for the "airlock" concept - the former balance chamber located under the test section of the original AWT configuration. A quick evaluation showed that, for relatively small models, such an approach would be feasible. This formed a basis for model handling concept No. 1 described later.

ii) Model Handling

At this stage it was clear that large models would often be tested and that any concept for the test section would have to enable these large models to be handled.

Handling of models, that is, their installation in the tunnel and subsequent removal, can be time-consuming if adequate provisions are not incorporated in the design. To achieve fast installation, the model should be brought into the test section, checked out and already mounted on the supports for attaching it to the model support systems located in the test section. This requirement is relatively basic for sting and sidewall-mounted models, but can be much more complicated for the strut-mounted models on external balance. The struts are usually directly supported by an external balance and are shielded by streamlined fairings that must be isolated from the live part of the balance.

If these components would have to be installed in the test section first, and then the model brought in and mounted onto the struts, it would be time consuming and not compatible with the requirement for high productivity. Therefore, the model support struts should be attached to the balance indirectly, through an adapter frame. This frame then serves an additional purpose of supporting the strut fairing turntable and an appropriate portion of the floor section during transportation from the model preparation area to the test section.

As this preliminary work proceeded, it became necessary to take into account at least basic aerodynamic requirements in developing the test section geometry.

c) Aerodynamic Considerations

i) Ventilated Wall and Plenum Diameter

Testing of aeronautical models at subsonic speeds requires a ventilated wall for two reasons:

- to minimize the aerodynamic interference of the wall on the model flowfield, so that corrections to measured quantities are small and thus reliable

- to compensate for model blockage and avoid choking at high subsonic speeds.

Special attention must be paid to these areas when large blockage models of the type envisaged here are to be tested.

The usual practise is to combine a slotted wall with a circular plenum surrounding the test section. Air flow into this plenum re-enters the circuit usually just down-stream of the test section -- this point will be dealt with later.

Consideration will now be given to the selection of slot size and plenum diameter. Slot size ultimately depends on the desired open area ratio, OAR, for which a value of 15% was suggested by NASA. This was briefly examined in the light of the high blockage (≈20%) models anticipated. From low interference and minimum choking considerations, it appears that 15% OAR is inadequate, and should therefore be substantially increased. According to the most recently published theory (Ref. 11) on the subject, an OAR of at least 20% would be required for low interference testing at high subsonic speeds. Clearly further study is required. For the current study, OAR = 15% was used in all analyses.

The slot width depends on OAR and number of slots. While it is acknowledged that a large number of slots is desirable because this reduces the perturbation on the overall flowfield due to local flow through the slot, only a total of 8 slots were selected here. This will facilitate design of model support structure, viewing windows, etc., and, according to early NACA work (Ref. 12), eight slots posed no great problems. Slot width should be increased gradually, over a distance of about 0.6 to 0.7 equivalent diameters.

Having arrived at a slotted wall geometry, a plenum diameter can be determined. The criterion used here was to keep the plenum wall far enough away from the "jet" issuing out of a wall slot such that it does not interfere aerodynamically with the jet. Following the experimental findings of Berndt (Ref. 13), which indicated that 5 jet diameters separation was adequate, the plenum diameter would have to be 1.66 equivalent test section diameters in this case. In the event a larger OAR slot was chosen, a further increase in plenum diameter would be necessary.

ii) Test Section Shape and Size

While the existing circular test section lends itself to testing a variety of shapes, e.g. axisymmetric bodies under zero lift conditions, it may not be the optimum shape overall. An octagonal cross-section is preferred for the following reasons:

- a flat floor is possible, which facilitates a turntable and external balance.

- the corners provide a convenient region to locate wall slots.

For proper development of transonic flow,a test section length of at least 2-1/2, preferably 2-3/4, diameters is required. In this regard the existing 2 diameter length is inadequate and should be examined further. The recommended length would enable the model pitch center to be located 0.65 lengths from the inlet, which allows the transonic flow to be developed smoothly and permits the wake blockage flow to be handled adequately. In this context it should be noted that although it may be possible to provide enough slot OAR to accommodate the large blockage models, there would be serious difficulties associated with longitudinal location of, say, an F-16 full-scale model. The nose of the aircraft should ideally not protrude into the initial slot width development region; so with a full-length aircraft in the 40 ft long test section, the tail would not be within the test section region.

iii) Plenum Re-entry Flow

The high flow rates into the plenum induced by the large blockage models envisaged by NASA must be returned to the diffuser just downstream of the test section. To ensure that there will be no restriction (especially choking) in the wall slots,the diffuser area at re-entry would have to be about 25% larger than the test section area. Control of the re-entry flow could be done through use of flaps, and here the octagonal test-section shape is quite convenient, i.e. 8 flaps could be used.

To accommodate both the recommended test section length increase and the diffuser re-entry flaps, plenum extensions ahead and behind the existing 40 ft. long region would be required. Since the outflow from wall slots will be low in these regions, a substantially reduced plenum diameter could be tolerated, which should enable a fairly simple construction method, e.g. form part of the diffuser structure.

If the test section length is to be increased, some of the increase can be obtained by ending the test section re-entry flaps at the point in the diffuser where the area has increased by 25%. Further, it is considered that the contraction could be shortened significantly without adversely affecting flow quality. If an octagonal shape is chosen for the test section, changes would be required in both the contraction and test section diffuser. The costs of any such changes have not been considered in this study.

From the above, the following conclusions were made for the purpose of the initial study.

- Octagonal cross-section of the test section would be used, with the area equivalent to that of a 20 ft. diameter circular section.

- The slotted wall would be enclosed in a plenum. Noting that the bottom part of the original test section is already contained in a "plenum" - the lower balance chamber - we decided to retain this arrangement and to add a semi-cylindrical plenum roof in the upper part of the test section.

- Length of the test section was left at 40 feet at this point. However, the potential problems that concern testing of models longer than the test section should be addressed during the next phase of test section design.

d) Development of Concepts

The geometry of the slotted walls and the size of plenum were defined and work started on the test section concepts.

The first concept (No. 1) was based on an assumption that models of smaller sizes, up to the length of about 12 feet, would be frequently tested. At that time, it was also thought that the external balance requirement may be removed from the specifications for the facility. The models would be mounted on struts or a sting.

To handle these relatively small, three-dimensional models, an airlock chamber mentioned previously is built inside the plenum below the test section. The concept is shown on drawing E44519, and it may be seen that the airlock chamber facilitates model handling (installation and removal) as well as quick access between tests.

The large models are installed and removed from above using the existing crane, with the plenum roof and a section of the slotted wall moved out of the way. In the proposed concept, the plenum roof is lifted upward and locked under the test hall roof which has to be raised by about 5 feet to allow implementation of this concept.

In the original AWT, the top part of the solid wall test section was hinged out of the way to enable installation or removal of models. This concept was briefly investigated, as shown on drawing E 44526. It may be seen that it does not offer any advantages as compared to the one described above, and has some disadvantages such as limited access into the test section and limited room for manoeuvering of models. Therefore, it was discarded.

During the development of the first concept, a number of telephone discussions with AWT project group members took place. It became clear that the large models, spanning the complete cross-section and supported at the sidewalls, were expected to be most frequently tested; therefore, our original assumption was not compatible with requirements. It was also indicated to us that the external balance below the test section was required and was to be capable of supporting either turntable-mounted or sidewall-mounted models.

Studies were continued,and the second concept is shown on drawing E 44520. Installation and removal of all the models takes place from above, with the plenum roof lifted up as shown on drawing E 44519. The strut-mounted models have to be brought in using a special lifting device. The external balance is located underneath the test section,and the sidewall-mounted models can be attached to it by means of a yoke structure as shown. When the turntable-mounted models are to be supported by the balance, the yoke is disconnected.

To facilitate quick access between tests to all models, the lower slanted sections of the slotted wall are hinged upwards 45^{0}. In this horizontal position, telescopic platforms, built into these two sections, are extended to form a continuous platform under the model.

Entrance into the test section is possible through a hatch in the sidewall structure which can be reached from a system of walkways inside the plenum. The test section floor and balance mounting face can be reached by another platform, extendable from a walkway.

Both concepts and the work that preceeded them were discussed at the 50% review meeting with NASA and were further considered by the AWT project group after the meeting.

e) Final Test Section Concept

When the AWT project group completed their review of the initial concepts discussed in the 50% review meeting, DSMA was given the following requirements outlining the preferred test section concept.

i) The slotted wall test section will have a circular cross-section and will be enclosed in a plenum.

ii) Models will be installed or removed either through the top of the test section or through the floor. Models removed through the floor will have a maximum length of 30 feet and a span of 20 feet. An airlock chamber will not be required.

iii) External balance and sting support to be provided underneath the test section. The balance will be used for testing strut-mounted full models or half models. The sting support would be used for scaled models.

iv) Full span, sidewall supported models will not be coupled to the balance but mounted onto a special model support system.

v) Quick access to models inside the test section will be accomplished using platforms under the models.

vi) The upper section of the test section and plenum cover will be stored above the test section diffuser when access through the top of the test section is required.

The final test section concept has been developed to satisfy these requirements.

The preferred concept of model handling through the top of the test section is essentially the same as that developed before the meeting. Only the final means of storage of the plenum roof assembly is different.

An assessment of the storage location above the test section diffuser was made,and the arrangement is shown on drawing E 45015.

Compared to storage directly above the test section, this concept offers greater safety. On the other hand, it is likely to be more costly to implement not only due to higher costs of hardware but also more extensive building modifications will be required.

However, the attention during this final stage of the study was focused on the area of much higher complexity i.e. through-the-floor model handling system.

Here, the various requirements listed above are closely related to each other. To achieve an effective and efficient solution, the model handling system must be integrated with the model/supports, and the resulting design must be compatible with easy access into the test section. Keeping this in mind, the conceptual work done previously was analyzed,and some basic decisions could be made on the design concept.

* External balance and sting model support will both be mounted on a common platform.
* The platform will be movable in a vertical direction, between two positions. In the lower position, the top of the platform and the model mounting interface of the balance will be at ground level.
  In the upper (operational) position, the top of the platform will be underneath the slotted wall. In this position, the platform will be locked to its supporting structure. See Drawing E45016.

* The bottom segment of the circular slotted wall of the test section will also be attached to the movable platform.
* The remaining segments of the test section lower part (excluding the three permanently fixed to the plenum roof) must swing out of the way to allow installation and removal of full 20 ft. span models. Consequently, the sidewall model support cannot be mounted on sidewalls, and a separate mounting structure must be provided.
* A large door in the plenum chamber underneath the test section will be necessary to install and remove the models.

The concept shown on drawings E 45015, E 45016 and E 45017 is the result of effort based on the above points together with the basic technical requirements outlined at the beginning of this section.

Before describing the details of this concept, a short discussion follows which will trace the development of the key element of the test section, the movable platform.

i) Movable Platform

Even a cursory examination of the functions of the platform shows that its size cannot be selected arbitrarily.

Given the size of the models to be handled through the test section floor, the length of the platform clearly depends on design of its support and guide columns. On the other hand, the width is a function of size of an external balance mounted on the platform.

As to the length, a number of schemes were quickly evaluated before the beginning of the final layout work and are shown on Figures 7 to 10.

The "long" platform, Figures 7 and 8, is supported by four columns standing inside the test section plenum, their bases being slightly below ground level. Requirements for clearance necessary for model transportation then dictate the clear distance between these columns to be in excess of 30 feet. Consequently, the depth of its structure and its weight will be considerable to ensure the stiffness necessary for satisfactory operation of the external balance. However, the platform guide and drive systems can be well integrated within the existing building,and excavations of depth approximately 25 feet below grade are required (locally, the cavity for the sting/strut will have to be deeper). See drawing E45016 and Fig. 7.

The "short" platform appears to be desirable for its lower weight (i.e. cost) while retaining stiffness equivalent to the "long" platform design. However, the support and guide columns must be moved underneath the platform. Otherwise, the model transport clearance cannot be achieved. Two variants of such a scheme are shown on Figures 9 and 10.

When the balance is standing on the platform as in Figure 9, very deep excavations are necessary and this makes the concept less attractive.

Suspending the balance from the top of the platform (Figure 10) improves the situation; however, in comparison with "long" platform, the drive system for the platform will be less accessible,and problems can be expected with lateral stiffness of the support columns.

Therefore, the concept of "long" platform was selected for further development; its length would be approximately 32 feet.

As to the width, the main requirement is that the structure of the movable platform must clear a cylindrical envelope swept by the external balance during yaw motion.

Recognizing that it is not possible to estimate dimensions of the external balance without a design study, a rough size was developed in-house.

Back-up information was obtained from a known manufacturer of external balances with whose design expert we discussed this application.

The first order estimate of the balance,based on technical requirements indicated by NASA,is:

- length and width 12 - 13 feet
- height 10 - 12 feet
- weight 30 - 40 tons

A swept cylinder diameter was taken as approximately 18 feet,and, as a result, the width of the platform was set at 24 feet. Diameter of balance turntable would be approximately 12 feet.

The platform is elevated by four synchronized screw actuators; their drive motor and interconnecting shafts are at the base of the support columns. Design of the columns will allow simple integration of the drive screws as well as the guiding system which utilizes Thomson "Roundway" bearings running on hardened ways.

When in the operation position, the platform will be locked to the columns to ensure the accuracy and repeatability of the external balance measurements.

During the evaluation of the movable platform schemes, the requirements for the sidewall model support were also taken into account.

It had been previously decided to mount the model support units on a special structure outside the test section slotted walls.

As it turned out, we were able to combine this structure with the guide columns for the movable platform. The model support units are mounted on the top of the resulting space frame. Their axial (streamwise) position is adjustable to suit different models. as shown on drawing E45016.

ii) Model Handling

Different methods will be necessary for handling of models, depending on the model support system used. It is assumed that models are prepared in adjacent preparation halls, and then transported to their model supports. Typical installation sequences of models into the proposed test section are described below.

For the sidewall mounted models, the plenum cover with top of the slotted wall is removed and stored. Then, the model is placed on and fastened to the model supports using the overhead crane,and the test section can be closed.

The sting mounted models are brought into the plenum chamber at ground level, on a transport cart. The movable platform is at the ground level and the sting support is positioned at a convenient height above ground so that the model with the sting can be connected onto the sting base attached to the strut. The installation is completed by removing the cart and closing the plenum door. Then, the movable platform can be raised to the operation height and locked.

The balance mounted models are assembled onto the support struts and adapter frame, including also the strut fairing assembly and a section of the bottom segment of the slotted test section. The complete arrangement is then transported into the plenum chamber and on the movable platform which is at ground level. Then, the strut fairing assembly and slotted wall section are disconnected from the adapter frame and fastened to the earth frame of the balance. In turn, the adapter frame is fastened to the 'live' mounting interfaces of the balance. The movable platform can be raised to its operating position, preceded by opening the sidewall segments of the slotted wall as required, to clear the model.

Removal of the models is accomplished by reversing the above described procedures. It is expected that exchange of models using the above systems should not require more than 1 shift, possibly with the exception of very large and complicated models.

The balance mounted models require the most complicated set-up. If frequency of testing of these models warrants it, consideration should be given to procurement of two or more adapter frame assemblies complete with model support struts, strut fairings and associated equipment. As shown on E 45017, a separate floor section will be required during tests of the sidewall mounted models, to replace the adapter frame.

Finally, a few words about means of transportation of the models from the preparation halls to the movable platform inside the plenum chamber.

> Rail transportation is one possibility - the cart for sting models and the adapter frame for strut (balance) mounted models can be provided with wheels and drive units. However, the rail system could become too complex and cumbersome if transport in two or more directions was required.

There is a modern method of omnidirectional transportation which has been successfully used by DSMA in design of a transportation system for large components of a low speed wind tunnel. That wind tunnel is now operational and the method - air bearing transport - has proven to be very successful in moving complete test sections and other heavy assemblies with weights of more than 220 tons.

The air bearing transport could be very usefully applied for transportation of models in the AWT. The weights involved are an order of magnitude lower than those mentioned above. On a sealed floor of average quality, approximately 2 lbs. force are required to move a 1000 lbs. load; thus, two men could probably transport even the heaviest expected loads.

To ensure safety of personnel and equipment, suitable means of guiding the components during transport would have to be provided. In addition, a "deadman" control is a standard on the available bearing systems - the air supply can be stopped very quickly, to stop the moving load in an emergency.

It should be noted that even the largest models can be handled in the preparation halls and transported to the crane pick-up point using this system.

It was concluded to use this system, and some aspects of it are shown on drawing E 45017.

iii) Access to Models

Access to the model will be required after each test run (retracting the model will be used for de-icing access), and the most important criterion for design of the means for access is that the tunnel down time should be minimized. Therefore, any preparatory operations should be automated and, where possible, should be initiated when the tunnel is being pressurized after the run.

Subsequently, when the tunnel conditions allow it, the desired components of the model should be reached as quickly as possible. After considering several different ideas, the preferred concept was developed and is indicated on drawing E45061.

The test section is entered through an opening at the upstream end of the slotted wall. This opening is covered by a remotely operated hatch during the tunnel operation and can be reached from the model preparation hall. Two alternate ways of reaching it have been shown:

- From ground level, a motorized access platform can be used. It is mounted on the side of the main movable platform.
- From the existing upper floor level, elevation 32' - 6", two staircases have to be used.

Selection of one of the above will be affected by the layout of the complete tunnel building and should be left to the next phase of the design.

Inside the test section, adjustable height platforms are formed by raising sections of the test section floor as required. These platforms are motorized and individually controlled from inside. Safety railings are retractable, manually operated and interlocked with the drive system for reasons of safety.

II.5 45 Ft. Test Section

The 45 ft. low speed test section will be used mainly for icing tests of full scale helicopters,and concepts for installation of these large models were included in the present study.

Before the 50% review meeting, a concept employing a large movable hatch in the bottom of the fan diffuser was prepared. Shown on drawing E44531 is the hatch already in its storage position. The model is wheeled into the opening, picked up by a hoist and placed on its support system. The remote-controlled hoist rides on a monorail which is suspended under the roof of the diffuser.

This concept is feasible; however, some potential problems were identified:

- The opening in the tunnel shell is large, and substantial reinforcement will be required. On the other hand, the size of the opening may be reduced when the design requirements have been better defined.

- Due to the close proximity of the small icing facility (IRT), trans-transportation of the models to the opening may be difficult and must be studied further.

At the review meeting, this concept was briefly reviewed,and NASA requested we investigate another concept based on an inclined ramp excavated underneath the fan diffuser.

A short study was made with the resultant layout shown on drawing E45018. A portion of tunnel shell, or flap, is hinged downward to form a continuous extension of the ramp. The model is pulled up the ramp and onto the flap which is then closed. The model is now inside the test section. This concept may be feasible; however, it was not developed any further. At the request of the AWT Project Group, work on the 45 ft. test section was terminated after the 50% review meeting. AWT Project Office is continuing this effort.

SECTION III
COST ESTIMATES

III COST ESTIMATES

The cost estimates prepared as part of this study are first level budgetary cost estimates.

For custom designed equipment such as the fan and components of the test section arrangement, the estimates are based on the design concepts developed. Hence,the degree of accuracy would depend on the degree to which the concept has been developed. The costs for structural and mechanical components were developed from the estimated weights and unit costs. The weight estimates are based on the conceptual layout developed during the study. The unit costs are based on actual costs of similar equipment designed by us and built in various countries and the cost data updated for escalation. The unit costs include material, shop fabrication, transportation to site, assembly and erection, checkout and operational tests.

For proprietary systems and equipment such as the fan drive, large couplings, bearings and similar, preliminary budget estimates were obtained from a number of suppliers, with adjustments for completeness in our estimates. For the external balance,a very preliminary cost estimate was obtained from one balance supplier,and this was based on a preliminary requirement definition.

The cost estimates are based on present day prices and do not include any allowance for cost escalation. There is no allowance for taxes, custom duty or similar cost additions.

The cost estimates essentially cover the areas of the wind tunnel facility considered in the study. They do not include modifications or additions to foundations and buildings. The estimates do not include costs of additional studies, any development costs,design and construction engineering and management.

The estimated costs are summarized as follows in thousands of dollars.

a) Fan Assembly

Fan housing including the outer housing, shaft fairing, nosecone, stator rings and tailcone	1 800
Rotors, including the blade attachment components	1 100
Rotor blades, including four (4) spares; laminated wood construction (total of 44 blades)	900
Fan rotor shaft and drive shaft	1 000
Couplings	100
Bearings	100
Associated systems, including bearing lubrication system and two vane actuating systems	600
Total	5 600

b) 20 Ft. Test Section Arrangement

Slotted wall test section assembly including the slotted wall components, their attachment structures, actuation systems, access hatches, windows and lighting	1 100
Plenum roof assembly including the roof structure, seals, locking mechanisms, lifting system	600
Movable platform and its support structure, including the drive system, locking systems and associated equipment	1 200
Allowance for additional model handling equipment	500
External balance and associated equipment (no calibration device)	2 800
Sting-strut model support system	1 800
Sidewall model support system (allowance)	1 000
Total	9 000

c) Fan Drive System

Including the drive motor, variable speed controller and installation. Two alternatives studied:

- 30,000 HP system without overload capability	4 400
- 30,000 HP system with overload capability to 45,000 HP	6 500

SECTION IV
DELIVERY TIMES

IV DELIVERY TIMES

Delivery times have been considered for major components and systems. For proprietary equipment they were obtained from suppliers,and for the custom designed equipment estimated by ourselves using most recent information obtained from industry on several other projects.

The delivery times indicated below cover a substantial part of the design concepts developed. However, complete equipment cannot be covered at this time,because it has not all been defined,and very likely there will be concept changes. This should provide general information which should be adequate for the general planning of the rehabilitation of the facility.

Fan drive system	18 months
Fan drive shaft components	12 months
Large gear type couplings	10 months
Large bearings	12 months
Fan blades (laminated wood construction)	16 months
Fan housing assembly including nosecone, center nacelle, tailcone, stator vanes, rotors and associated equipment	18 months
Slotted wall test section assembly including plenum roof and elevated platform	20 months
External balance system	20 months
Strut/sting model support system	18 months

The above estimates do not include any time for demolition of existing equipment and time for site preparation.

SECTION V
CONCLUSIONS AND RECOMMENDATIONS

V CONCLUSIONS AND RECOMMENDATIONS

The main conclusions of this study are:

a) Circuit Losses: The circuit losses estimated in this study are considered reasonable and are consistent with data for other wind tunnels operating in the same Mach number regime. Prior to the final estimation of circuit losses, some points need to be addressed, namely:

i) definition of flow quality requirements for both test sections and investigation of methods of achieving them,considering the effects on circuit losses and protection from icing.

ii) definition of heat exchanger configuration which is dependent on the refrigeration system to be used. As above, the effects on flow quality and losses, and protection from icing must be considered.

iii) consideration of the range of models to be tested and the associated model support systems over the complete Mach number range.

b) Fan: A 31' diameter,two stage,fixed pitch fan with a variable speed drive will best meet the requirements of the rehabilitated AWT. It may be possible to improve efficiency at off-design points by using variable inlet guide vanes and inter-rotor stators, but an assessment of advantages and disadvantages cannot be done until final fan design data are available.

Conceptual mechanical design studies indicate that a two stage fan with fixed pitch rotor blades and variable inlet guide vanes and inter-rotor stators is feasible. There are no serious problems anticipated in design or in construction of all the major fan components. There are areas, however, which should be given special attention during the preliminary design, and these are:

- the blade tip seals and provisions to cope with lumps of ice should be thoroughly investigated
- the overall fan design considerations should include studies of assembly sequences with limitations for handling of major components within the tunnel shell
- with variable speed fan it will be necessary to run through one or two of the lowest lateral frequencies of the fan blades. This should be carefully studied in relation to the operating envelopes, and necessary steps should be taken to minimize the effect on the operating speed range.

c) Fan Drive (Electrical/Controls Study): While the fixed speed drive has been evaluated during the study, it is eliminated from final consideration as a result of the final fan design concept.

Of the variable speed drives evaluated, the synchronous AC motor with a variable frequency speed control system is preferred from a performance point of view. The wound rotor motor with the slip power recovery is the most expensive, while the wound rotor motor with a liquid rheostat has poor performance and a very narrow speed range.

While the load carrying capability of the drive motor support foundation cannot be reasonably evaluated, it appears that this will be too small to support a considerably larger size motor. Also, the drive building will be too small.

d) 20 Ft. Test Section: The studies of the 20 ft. test section arrangement with the multiple model support systems and model handling provisions aimed at high productivity resulted in a versatile, but quite complex arrangement. Before proceeding with the preliminary design of this equipment further, more detailed studies should be conducted as follows:

i) The complete range of models and anticipated test programs should be evaluated to establish which of the features in the test section arrangement, model support and handling system - are of most value. This information should then be used to establish priorities in the development of further design.

ii) Further studies in more detail should be conducted on the test section arrangement considering the following major areas.

- test section length
- slotted wall open area, slot shape and location
- mechanism for providing plenum re-entry flow into the diffuser
- access through the top of the test section, either to raise the plenum roof vertically or slide it over the test section diffuser
- the need for an external balance as compared to a simpler, more compact internal balances
- the balance elevating platform and the large, strut mounted model handling provisions together with modifications to the existing structures

- access to models in the test section
- the test section geometry, cylindrical and octagonal with consideration for windows, turntables, and use of walls as model access platforms.

iii) Studies on associated building modifications necessary for implementation of the high productivity test section arrangement.

REFERENCES

REFERENCES

1. Contract NAS3-22933
   Modification of Altitude Wind Tunnel for Icing and Propulsion Research Study Part A

2. Statement of Work 3-169855 revised 2/20/81

3. Preliminary Draft
   "General Requirements and Design Criteria"

4. D.P. Kenny, "A Turbulent Boundary Layer Analysis of Conical Diffusers", from Canadian Aeronautics and Space Institute Transactions, September, 1974.

5. Francis X. Dolan and Peter W. Runstadler, Jr., "Pressure Recovery Performance of Conical Diffusers at High Subsonic Mach Numbers", NASA CR-2299, August 1973.

6. J.E. Green, D.J. Weeks, J.W.F. Brooman, "Prediction of Turbulent Boundary Layers and Wakes in Compressible Flow by a Lag-Entrainment Method", Royal Aircraft Establishment, Technical Report 72231, January 1973.

7. K.G. Winter and L. Gaudet, "Turbulent Boundary-Layer Studies at High Reynolds Numbers at Mach Numbers Between 0.2 and 2.8" ARC R&M3712, December 1970, Aeronautical Research Council, London, England.

8. R. Ross and P.B. Rohne, "Model Support Noise in the NLR Transonic Wind Tunnel", STA Paper AC-78-002, Paper prepared for presentation at 49th semi-annual meeting at STA, El Segundo, California, April 1978.

9. W.J. Duncan, A.S. Thom and A.D. Young, "Mechanics of Fluids", Edward Arnold (Publishers) Ltd., London, England, 1970

10. S.F. Hoerner, "Fluid-Dynamic Drag", Hoerner Fluid Dynamics, U.S.A. 1965.

11. K.R. Karlsson and Y.C.-J. Sedin, "Numerical Design and Analysis of Optimal Slot Shapes for Transonic Test Sections -- Axisymmetric Flows", AIAA J. Aircraft, Vol. 18, No. 3, pp. 168-175, 1981.

12. B.H. Goethert, "Transonic Wind Tunnel Testing", Pergamon Press, New York, 1961

13. S.B. Berndt and H. Sörensen, "Flow Properties of Slotted Walls for Transonic Test Sections", AGARD-CP-174, Paper 17, 1975

TABLES

LEWIS AWT LOSSES - SLOTTED T/S - M=0.2, H=30000.FT.

TEST SECTION CONDITIONS

MACH NUMBER - 0.2000
TOTAL PRESSURE - 0.3094 BARS
TOTAL TEMPERATURE - 230.8000 DEG.K.
CHORD REYNOLDS NUMBER - 1.0078 MILLIONS

FAN

LOSS FACTOR(DPTF/QTS) - 0.5266
TOTAL PRESSURE RISE - 0.0044 BARS
AIR POWER - 974.6521 KW
EFFICIENCY - 0.7900
(PTFO/PTFI) - 1.0144
(RMF*SQRT(TRFI)/PRFI) - 2395.6979
CIRCUIT TRANSIT TIME - 11.2016 SEC.
EQUIV. CONTRACTION L. - 8.2000 M.
PLENUM BLOCKAGE - 0.0172
TUNNEL MASS FLOW - 811.2699 KGR./SEC.
FAN INLET UNIT RE. - 1.0303 ~~MILLIONS/M.~~
FAN OUTLET BLOCKAGE - 3.0000 PERCENT
FAN DIFFUSER BLOCKAGE - 8.3147 PERCENT

	AREA	M	PT	PS	TT	TS	U	LOSS FACTORS	
	SQ.M.		BARS		DEG.K.		M./SEC.	LOCAL	T/S
STRUT/MODEL	29.225	0.2000	0.3094	0.3009	230.800	228.968	60.627	0.0260	0.0260
T/S DIFFUSER	30.093	0.1939	0.3092	0.3012	230.800	229.078	58.782	0.1068	0.1004
CORNER 1	53.197	0.1083	0.3083	0.3058	230.800	230.260	32.916	0.1300	0.0387
CROSSLEG 1	53.197	0.1084	0.3080	0.305'	230.800	230.259	32.952	0.2069	0.0617
CORNER 2	70.584	0.0816	0.3075	0.3061	230.800	230.493	24.813	0.2300	0.0389
FAN INLET	70.584	0.0817	0.3072	0.3057	230.800	230.493	24.839	0.0047	0.0008
FAN	52.604	0.1099	0.3072	0.3046	230.800	230.243	33.420	-1.7164	-0.5250
FAN TAILCONE	52.604	0.1086	0.3116	0.3090	231.745	231.199	33.078	0.1211	0.0367
SCREEN	133.551	0.0426	0.3113	0.3109	231.745	231.661	12.977	1.0000	0.0468
FAN DIFFUSER	133.551	0.0426	0.3109	0.3105	231.745	231.661	12.993	0.1481	0.0069
CORNER 3	189.667	0.0300	0.3108	0.3106	231.745	231.703	9.147	0.1300	0.0030
CROSSLEG 2	189.667	0.0300	0.3108	0.3106	231.745	231.703	9.148	0.0025	0.0001
HEAT EXCHANGER	189.667	0.0300	0.3108	0.3106	231.745	231.703	9.148	2.5000	0.0581
CORNER 4	189.667	0.0300	0.3103	0.3101	230.800	230.759	9.125	0.1300	0.0030
SETTLING CHAMBER	189.667	0.0300	0.3103	0.3101	230.800	230.758	9.127	3.0035	0.0694
CONTRACTION	189.667	0.0300	0.3097	0.3095	230.800	230.758	9.144	0.0105	0.0002
TEST SECTION	29.225	0.1996	0.3097	0.3012	230.800	228.975	60.509	0.0373	0.0372

TABLE 1A

LEWIS AWT LOSSES - SLOTTED T/S - M=0.38, SEA LEVEL.

TEST SECTION CONDITIONS

MACH NUMBER	-	0.3800
TOTAL PRESSURE	-	1.1194 BARS
TOTAL TEMPERATURE	-	301.5000 DEG.K.
CHORD REYNOLDS NUMBER	-	4.6801 MILLIONS

FAN

LOSS FACTOR(DPTF/QTS)	-	0.4849
TOTAL PRESSURE RISE	-	0.0496 BARS
AIR POWER	-	21606.8848 KW
EFFICIENCY	-	0.8200
(PTFO/PTFI)	-	1.0453
(RMF*SQRT(TRFI)/PRFI)	-	4347.0506
CIRCUIT TRANSIT TIME	-	5.4516 SEC.
EQUIV. CONTRACTION L.	-	7.6400 M.
PLENUM BLOCKAGE	-	0.0145
TUNNEL MASS FLOW	-	4588.2347 KGR./SEC.
FAN INLET UNIT RE.	-	4.7320 MILLIONS/M.
FAN OUTLET BLOCKAGE	-	3.0000 PERCENT
FAN DIFFUSER BLOCKAGE	-	8.3147 PERCENT

	AREA	M	PT	PS	TT	TS	U	LOSS FACTORS	
	SQ.M.		BARS		DEG.K.		M./SEC.	LOCAL	T/S
STRUT/MODEL	29.225	0.3800	1.1194	1.0132	301.500	293.037	130.314	0.0315	0.0315
T/S DIFFUSER	30.093	0.3677	1.1162	1.0167	301.500	293.563	126.202	0.0833	0.0782
CORNER 1	53.197	.1980	1.1082	1.0783	301.500	299.155	68.598	.1300	0.0376
CROSSLEG 1	53.197	0.1987	1.1043	1.0743	301.500	299.138	68.841	0.2086	0.0605
CORNER 2	70.584	0.1490	1.0981	1.0812	301.500	300.167	51.726	0.2300	0.0378
FAN INLET	70.584	.1496	1.0943	1.0773	301.500	300.157	51.912	.0038	0.0006
FAN	52.604	0.2030	1.0942	1.0632	301.500	299.036	70.320	-1.6177	-0.4844
FAN TAILCONE	52.604	0.1950	1.1438	1.1139	305.344	303.038	68.020	0.1063	0.0308
SCREEN	133.551	0.0756	1.1406	1.1361	305.344	304.996	26.437	.0000	0.0443
FAN DIFFUSER	133.551	0.0759	1.1361	1.1315	305.344	304.993	26.544	0.1448	0.0064
CORNER 3	189.667	0.0534	1.1354	1.1332	305.344	305.170	18.675	0.1300	0.0029
CROSSLEG 2	189.667	0.0534	1.1352	1.1329	305.344	305.170	18.682	0.0026	0.0000
HEAT EXCHANGER	189.667	0.0534	1.1351	1.1329	305.344	305.170	18.682	2.5000	0.0552
CORNER 4	189.667	0.0533	1.1295	1.1273	301.500	301.329	18.538	0.1300	0.0029
SETTLING CHAMBER	189.667	0.0533	1.1292	1.1270	301.500	301.329	18.544	3.0028	0.0658
CONTRACTION	189.667	0.0537	1.1225	1.1202	301.500	301.327	18.657	0.0085	0.0002
TEST SECTION	29.225	0.3783	1.1225	1.0169	301.500	293.111	129.745	0.0309	0.0309

TABLE 1B

LEWIS AWT LOSSES - SLOTTED T/S - M=0.8, H=47000.FT.

TEST SECTION CONDITIONS

MACH NUMBER	-	0.8000
TOTAL PRESSURE	-	0.2056 BARS
TOTAL TEMPERATURE	-	245.9000 DEG.K.
CHORD REYNOLDS NUMBER	-	1.9290 MILLIONS

FAN

LOSS FACTOR(DPTF/QTS)	-	0.5093
TOTAL PRESSURE RISE	-	0.0308 BARS
AIR POWER	-	18564.6671 KW
EFFICIENCY	-	0.8800
(PTFO/PTFI)	-	1.1641
(RMF*SQRT(TRFI)/PRFI)	-	7439.7660
CIRCUIT TRANSIT TIME	-	3.6813 SEC.
EQUIV. CONTRACTION L.	-	6.3000 M.
PLENUM BLOCKAGE	-	0.0216
TUNNEL MASS FLOW	-	1490.8059 KGR./SEC.
FAN INLET UNIT RE.	-	1.8334 MILLIONS/M.
FAN OUTLET BLOCKAGE	-	3.0000 PERCENT
FAN DIFFUSER BLOCKAGE	-	8.3147 PERCENT

	AREA	M	PT	PS	TT	TS	U	LOSS FACTOR*	
	SQ.M.		BARS		DEG.K.		M./SEC.	LOCAL	T/S
STRUT/MODEL	29.225	0.8000	0.2056	0.1349	245.900	217.996	236.626	0.0570	0.0570
T/S DIFFUSER	30.093	0.7688	0.2022	0.1367	245.900	219.908	228.377	0.1296	0.1213
CORNER 1	53.197	0.3466	0.1948	0.1793	245.900	240.132	107.586	0.1300	0.0324
CROSSLEG 1	53.197	0.3507	0.1929	0.1771	245.900	239.996	108.840	0.2137	0.0539
CORNER 2	70.584	0.2602	0.1896	0.1809	245.900	242.614	81.203	0.2300	0.0326
FAN INLET	70.584	0.2632	0.1876	0.1788	245.900	242.540	82.116	0.0045	0.0006
FAN	52.604	0.3671	0.1876	0.1709	245.900	239.446	113.801	-1.9088	-0.5094
FAN TAILCONE	52.604	0.3157	0.2184	0.2038	256.809	251.790	100.356	0.1178	0.0277
SCREEN	133.551	0.1191	0.2167	0.2146	256.809	256.082	38.188	1.0000	0.0353
FAN DIFFUSER	133.551	0.1203	0.2146	0.2124	256.809	256.067	38.575	0.1474	0.0053
CORNER 3	189.667	0.0845	0.2143	0.2132	256.809	256.443	27.102	0.1300	0.0023
CROSSLEG 2	189.667	0.0845	0.2141	0.2130	256.809	256.442	27.118	0.0023	0.0000
HEAT EXCHANGER	189.667	0.0845	0.2141	0.2130	256.809	256.442	27.118	2.5000	0.0441
CORNER 4	189.667	0.0838	0.2114	0.2104	245.900	245.556	26.291	0.1300	0.0022
SETTLING CHAMBER	189.667	0.0838	0.2113	0.2103	245.900	245.555	26.309	3.0032	0.0514
CONTRACTION	189.667	0.0851	0.2082	0.2072	245.900	245.545	26.704	0.0098	0.0002
TEST SECTION	29.225	0.7684	0.2082	0.1409	245.900	219.927	228.294	0.0444	0.0429

TABLE 1C

LEWIS AWT LOSSES - SLOTTED T/S - M=0.9, H=55000.FT.

TEST SECTION CONDITIONS

MACH NUMBER	-	0.9000
TOTAL PRESSURE	-	0.1592 BARS
TOTAL TEMPERATURE	-	253.3000 DEG.K.
CHORD REYNOLDS NUMBER	-	1.5146 MILLIONS

FAN

LOSS FACTOR(DPTF/QTS)	-	0.5570
TOTAL PRESSURE RISE	-	0.0297 BARS
AIR POWER	-	19766.4023 KW
EFFICIENCY	-	0.8500
(PTFO/PTFI)	-	1.2118
(RMF*SQRT(TPFI)/PRFI)	-	7921.9044
CIRCUIT TRANSIT TIME	-	3.4848 SEC.
EQUIV. CONTRACTION L.	-	6.0000 M.
PLENUM BLOCKAGE	-	0.0244
TUNNEL MASS FLOW	-	1170.4804 KGR./SEC.
FAN INLET UNIT RE.	-	1.4100 MILLIONS/M.
FAN OUTLET BLOCKAGE	-	3.0000 PERCENT
FAN DIFFUSER BLOCKAGE	-	8.3147 PERCENT

	AREA	M	PT	PS	TT	TS	U	LOSS FACTORS	
	SQ.M.		BARS		DEG.K.		M./SEC.	LOCAL	T/S
STRUT/MODEL	29.225	0.9000	0.1592	0.0941	253.300	217.986	266.198	0.0890	0.0890
T/S DIFFUSER	30.093	0.8986	0.1544	0.0915	253.300	218.081	265.840	0.1527	0.1479
CORNER 1	53.197	0.3709	0.1466	0.1333	253.300	246.518	116.661	0.1300	0.0313
CROSSLEG 1	53.197	0.3760	0.1449	0.1314	253.300	246.335	118.221	0.2148	0.0523
CORNER 2	70.584	0.2783	0.1421	0.1347	253.300	249.436	88.054	0.2300	0.0315
FAN INLET	70.584	0.2820	0.1404	0.1329	253.300	249.336	89.190	0.0047	0.0007
FAN	52.604	0.3959	0.1404	0.1260	253.300	245.599	124.308	-2.1500	-0.5570
FAN TAILCONE	52.604	0.3261	0.1701	0.1580	267.590	262.018	105.738	0.1211	0.0267
SCREEN	133.551	0.1227	0.1687	0.1669	267.590	266.787	40.147	1.0000	0.0330
FAN DIFFUSER	133.551	0.1240	0.1669	0.1651	267.590	266.770	40.578	0.1480	0.0049
CORNER 3	189.667	0.0871	0.1667	0.1658	267.590	267.185	28.507	0.1300	0.0021
CROSSLEG 2	189.667	0.0871	0.1665	0.1657	267.590	267.185	28.529	0.0024	0.0000
HEAT EXCHANGER	189.667	0.0871	0.1665	0.1657	267.590	267.185	28.529	2.5000	0.0412
CORNER 4	189.667	0.0859	0.1643	0.1635	253.300	252.927	27.365	0.1300	0.0021
SETTLING CHAMBER	189.667	0.0860	0.1642	0.1634	253.300	252.926	27.386	3.0034	0.0476
CONTRACTION	189.667	0.0873	0.1617	0.1608	253.300	252.914	27.819	0.0101	0.0002
TEST SECTION	29.225	0.8332	0.1617	0.1026	253.300	222.418	248.934	0.0499	0.0466

TABLE 1D

Comparison of Operating Boundaries
Variable Pitch vs Variable Speed
25,000 HP

Altitude ft.	Mach Number	
	Variable Pitch	Variable Speed
Sea Level	0.37	0.29
47,000	0.80	0.80
55,000	0.88	0.88

Table 2.

Comparison of Operating Boundaries
Variable Speed Drive

Altitude ft.	Mach Number		
	25,000 HP	30,000 HP	45,000 HP
Sea Level	0.29	0.31	0.35
47,000	0.80	0.84	0.93
55,000	0.88	0.92	1.00

Table 3.

Drive System	Drive Cost			Starting Network	Installation Cost	Total Cost Drive Installed
	30,000HP Without O/L 1	30,000HP 20% O/L 1 hr. 2	30,000HP 50% O/L 1/2hr. 3			
A.C. Wound Rotor Motor With Starting Liquid Rheostat	2,080,000	2,453,000	3,012,000	–	1 625,000	1 2,705,000
					3 903,000	3 3,915,000
A.C. Synchronous Motor With Variable Frequency Starter	1,530,000	1,803,000	2,212,000	1 150,000	1 444,000	1 2,124,000
				3 175,000	3 641,000	3 3,028,000

Table 4 Fixed Speed Drive Cost Estimates For Drive System

Motor Type	30,000HP Without O/L Capability	30,000HP 20% O/L	30,000 50% O/L For 1/2 hr.
Wound Rotor Motor	1,980,000	2,343,000	2,887,000
Synchronous Motor	1,320,000	1,551,000	1,897,000

Table 5 Cost Estimates For Motor

Control System	30,000HP Without O/L. Capability	30,000HP 20% O/L For 1 hr.	30,000HP 50% O/L For 1/2 hr.
Liquid Rheostat	450,000	540,000	675,000
Static Slip Energy Recovery System	1,800,000	2,160,000	2,700,000
Variable Frequency Control	2,100,000	2,520,000	3,150,000

Table 6 Variable Speed Drive. Cost Estimates For Control Equipment

Drive System	Drive Cost			Installation Cost	Total Cost Drive Installed
	30,000 HP Without O/L Capability 1	30,000 HP 20% O/L 1hr.	30,000 HP 50% O/L 1/2 hr. 3		
A.C. Wound Rotor Motor With Liquid Rheostat	2,430,000	2,883,000	3,562,000	1 900,000	1 3,330,000
				3 1,318,000	3 4,880,000
A.C. Wound Rotor Motor With Slip Energy Recovery System	3,780,000	4,503,000	5,587,000	1 1,100,000	1 4,780,000
				3 1,464,000	3 7,051,000
A.C. Synchronous Motor With Variable Frequency Control	3,420,000	4,071,000	5,047,000	1 1,000,000	1 4,420,000
				3 1,464,000	3 6,511,000

Table 7 Variable Speed Drive. Cost Estimates For Drive System

Speed %	Efficiency %	Assumed Duty Cycle		Total Operating Costs		Energy Losses	
		Hrs/Day	Days/Year	Kwh	$*	Kwh	$*
100	90	2.5	50	3,108,333	124,333	310,833	12,433
90	80	2.5	50	2,550,000	102,000	510,000	20,400
80	71	2.5	50	2,017,605	80,704	585,106	23,404
70	61.5	2.5	50	1,560,975	62,439	600,976	24,039
Total Per Year				9,236,913	369,476	2,006,915	80,276

* Assumed 4¢/Kwh

Table 8 Variable Speed Drive. Operating Cost And Energy Losses Per Year For Wound Rotor Motor With Liquid Rheostat (30,000HP Output)

Speed %	Efficiency %	Assumed Duty Cycle		Total Operating Costs		Energy Losses	
		Hrs/Day	Days/Year	Kwh	$*	Kwh	$*
100	90	2.5	50	3,108,333	124,333	310,233	12,433
90	89	2.5	50	2,292,135	91,685	252,135	10,085
80	88	2.5	50	1,627,841	65,114	195,341	7,814
70	84	2.5	50	1,142,857	45,714	182,857	7,314
Total Per Year				8,171,166	326,846	941,166	37,646

* Assumed 4¢/Kwh

Table 9 Variable Speed Drive. Operating Cost And Energy Losses Per Year For Wound Rotor Motor With Slip Energy Recovery System (30,000 HP)

Speed %	Efficiency %	Assumed Duty Cycle		Total Operating Cost		Energy Losses	
		Hrs Day	Days Year	Kwh	$ *	Kwh	$ *
100	90	2.5	50	3,108,333	124,333	310,833	12,433
90	90	2.5	50	2,266,667	90,667	226,667	9,067
80	89.5	2.5	50	1,600,559	64,022	168,059	6,722
70	89	2.5	50	1,078,652	43,146	118,652	4,746
Total per Year				8,054,211	322,168	824,211	32,968

*Assumed 4¢/Kwh

Table 10 Variable Speed Drive Operating Costs And Energy Losses Per Year For Synchronous Motor With Variable Frequency Control (30,000 HP)

Drive System	Operating Cost* Per Year	Energy Loss* Per Year
A.C. Wound Rotor Motor With Liquid Rheostat	369,476	80,276
A.C. Wound Rotor Motor With Slip Energy Recovery System	326,846	37,646
A.C. Synchronous Motor With Variable Frequency Control	322,168	32,968

* For Assumed Duty Cycle And 4¢/Kwh

Table 11 Variable Speed Drive. Operating Cost And Energy Losses Per Year

Drive System	Speed Control Range	Speed Control Accuracy	Starting Current	Regulation	Transient Response	Comments
A.C. Wound Rotor Motor With Liquid Rheostat	3:1	Fair	Max. 125% FLC	Fair	Poor	Very Low Efficiency Narrow Speed Range
A.C. Wound Rotor Motor With Static Slip Recovery System	10:1	Good	Less Than FLC	Good	Fair	Good Efficiency Power Factor & Harmonics Considerations
A.C. Synchronous Motor With Variable Frequency Control	20:1	Very Good	Less Than FLC	Very Good	Good	Very Good Efficiency Very Flexible System Power Factor & Harmonics Considerations

Table 12 Variable Speed Drive.Summary Of Drive Systems Performances

FIGURES

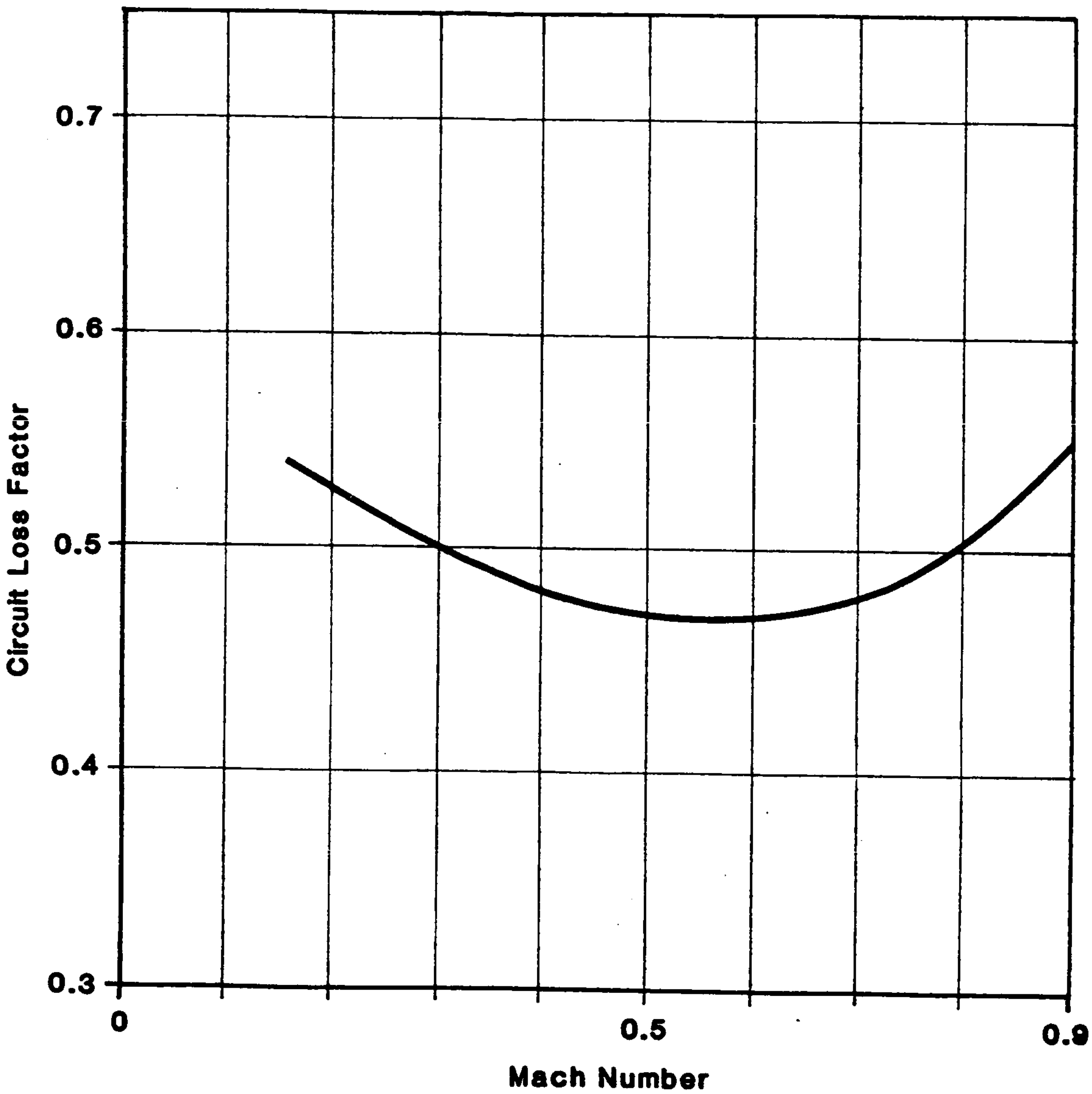


Figure 1 Predicted Circuit Loss Factors

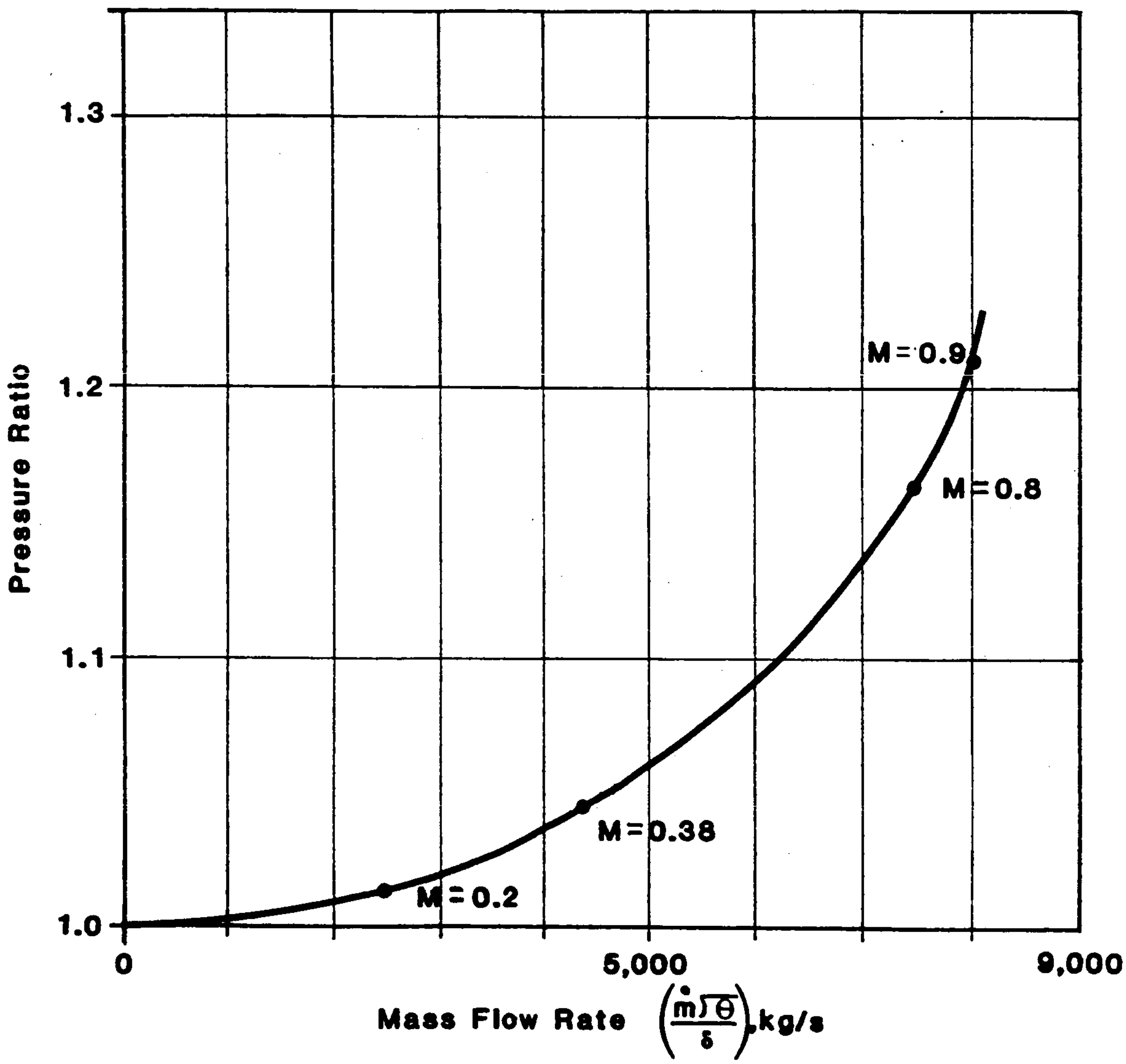


Figure 2 Predicted Fan Load Line

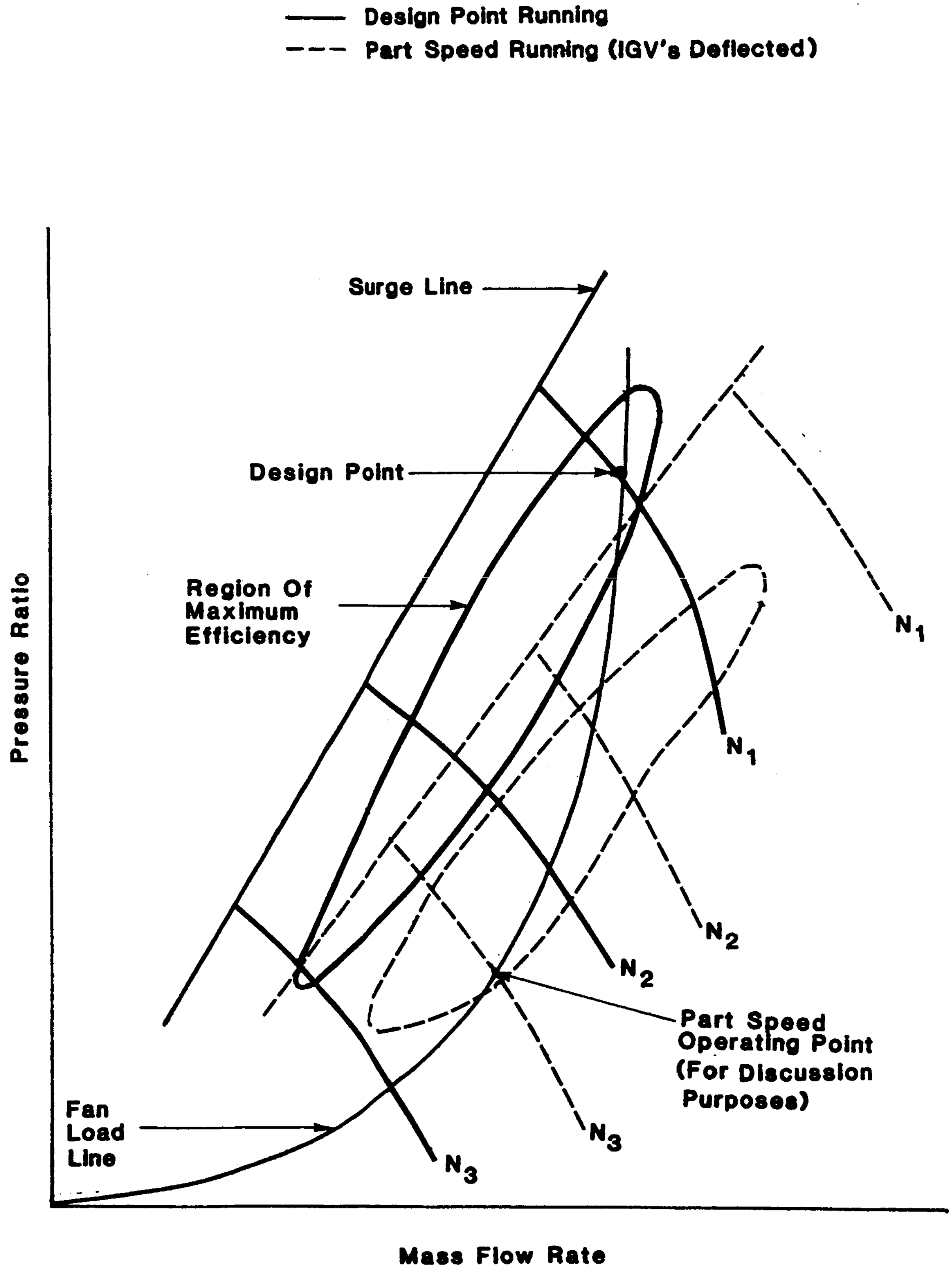


Figure 3 Schematic Fan Map

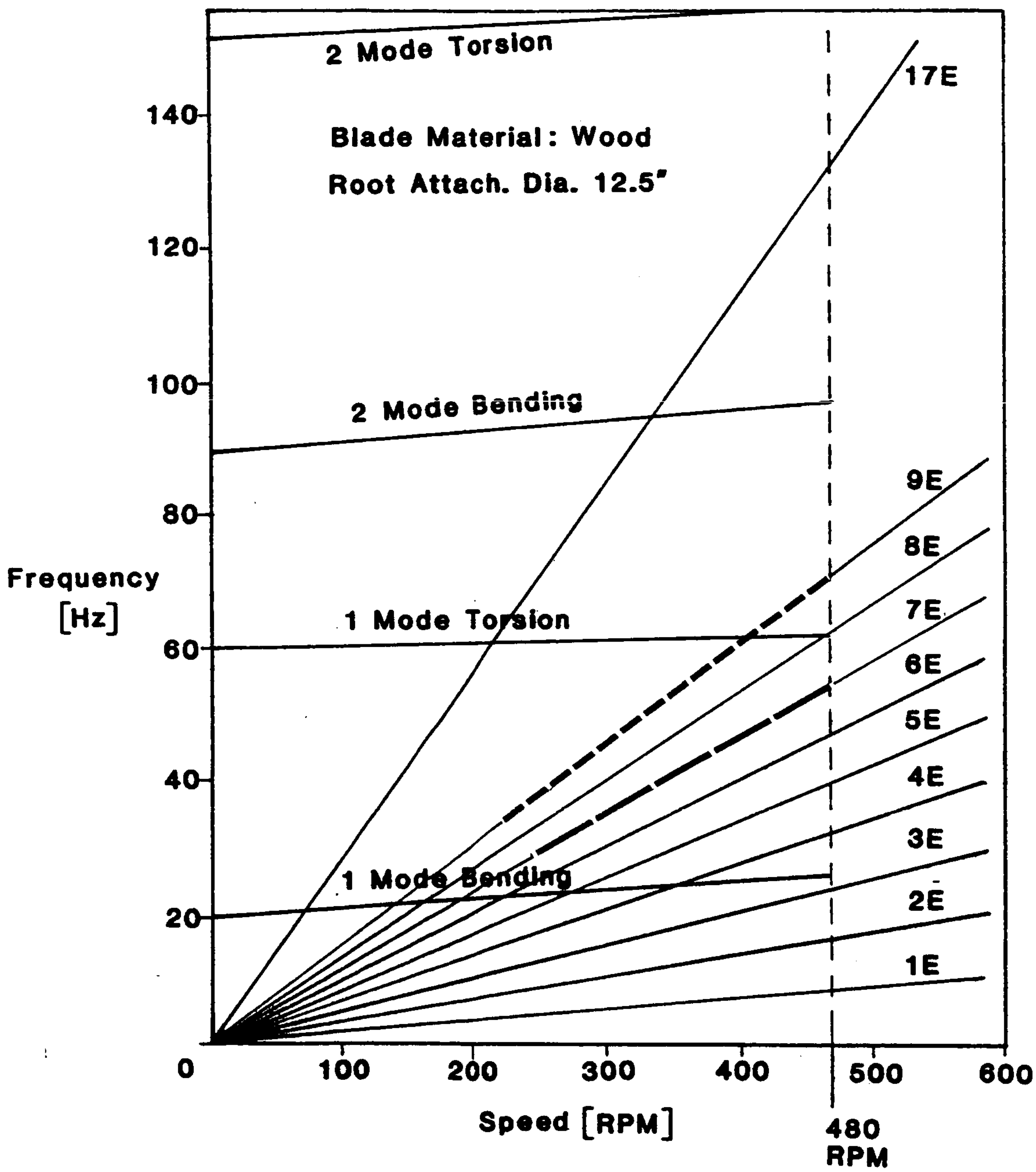


Figure 4 Fan Blade Interference Diagram

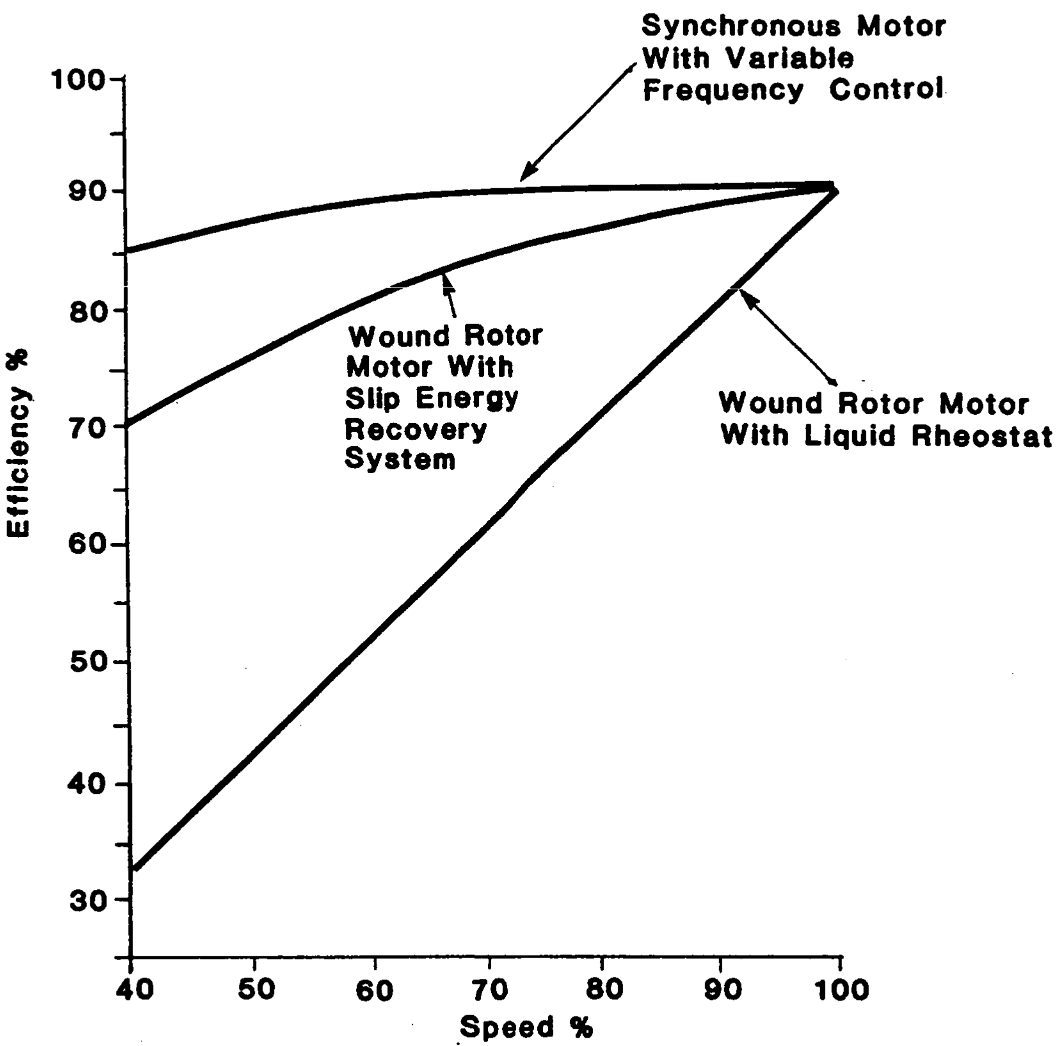


Figure 5 Variable Speed Drive Systems
Efficiency Comparisons

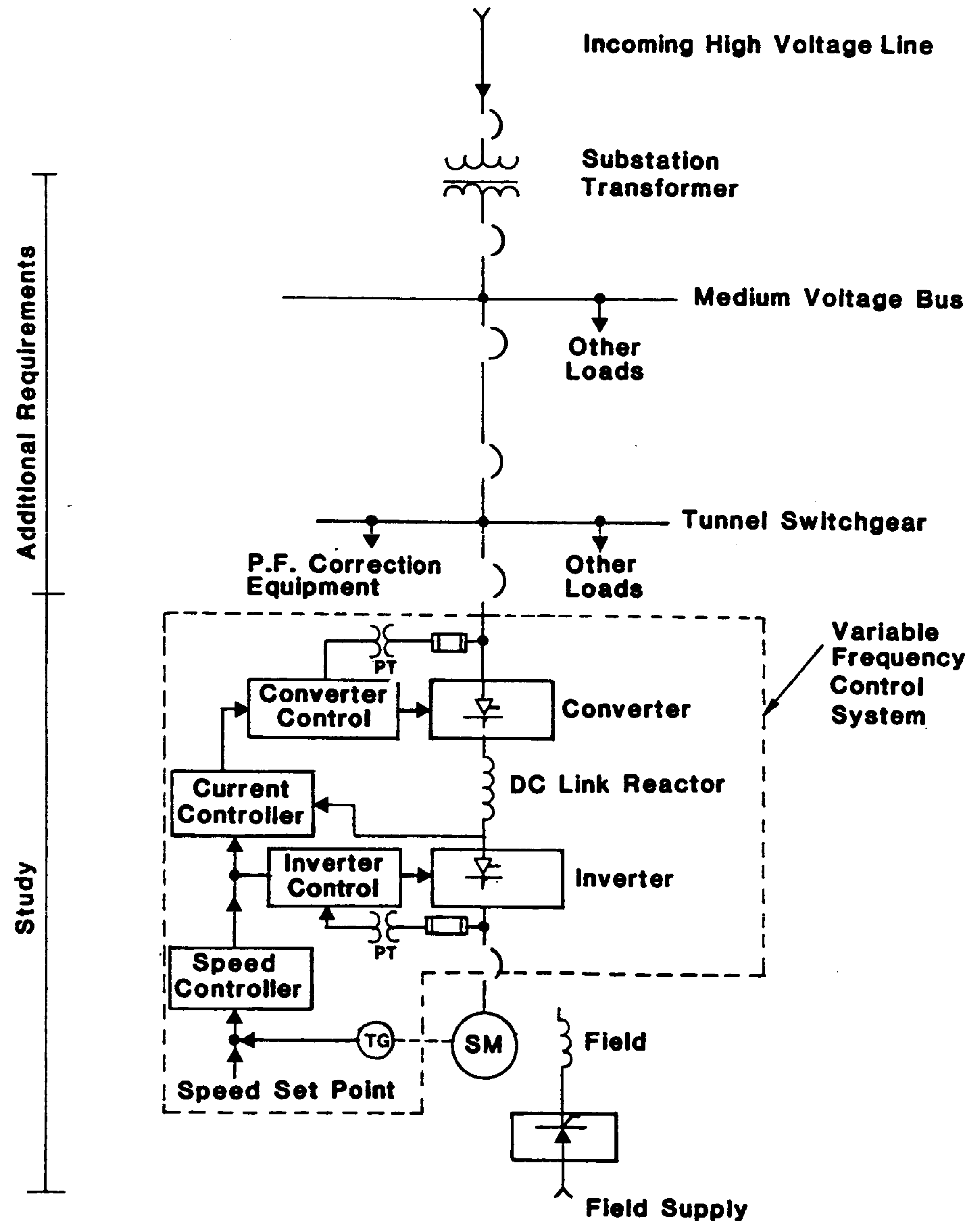


Figure 6. Variable Speed Drive. Synchronous Motor With Variable Frequency Control. Block Diagram

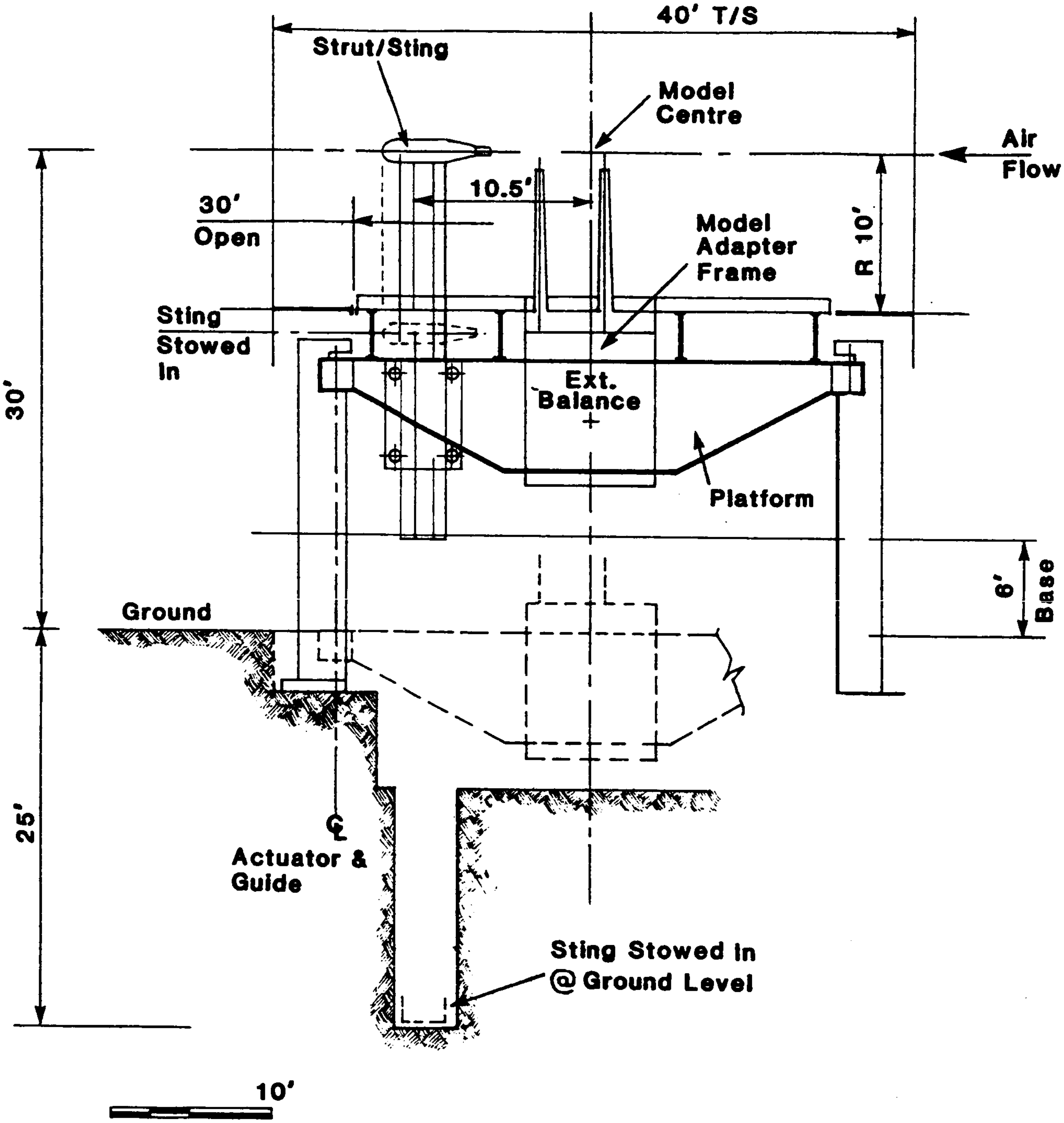


Figure 7 "Long" Platform Elevation View

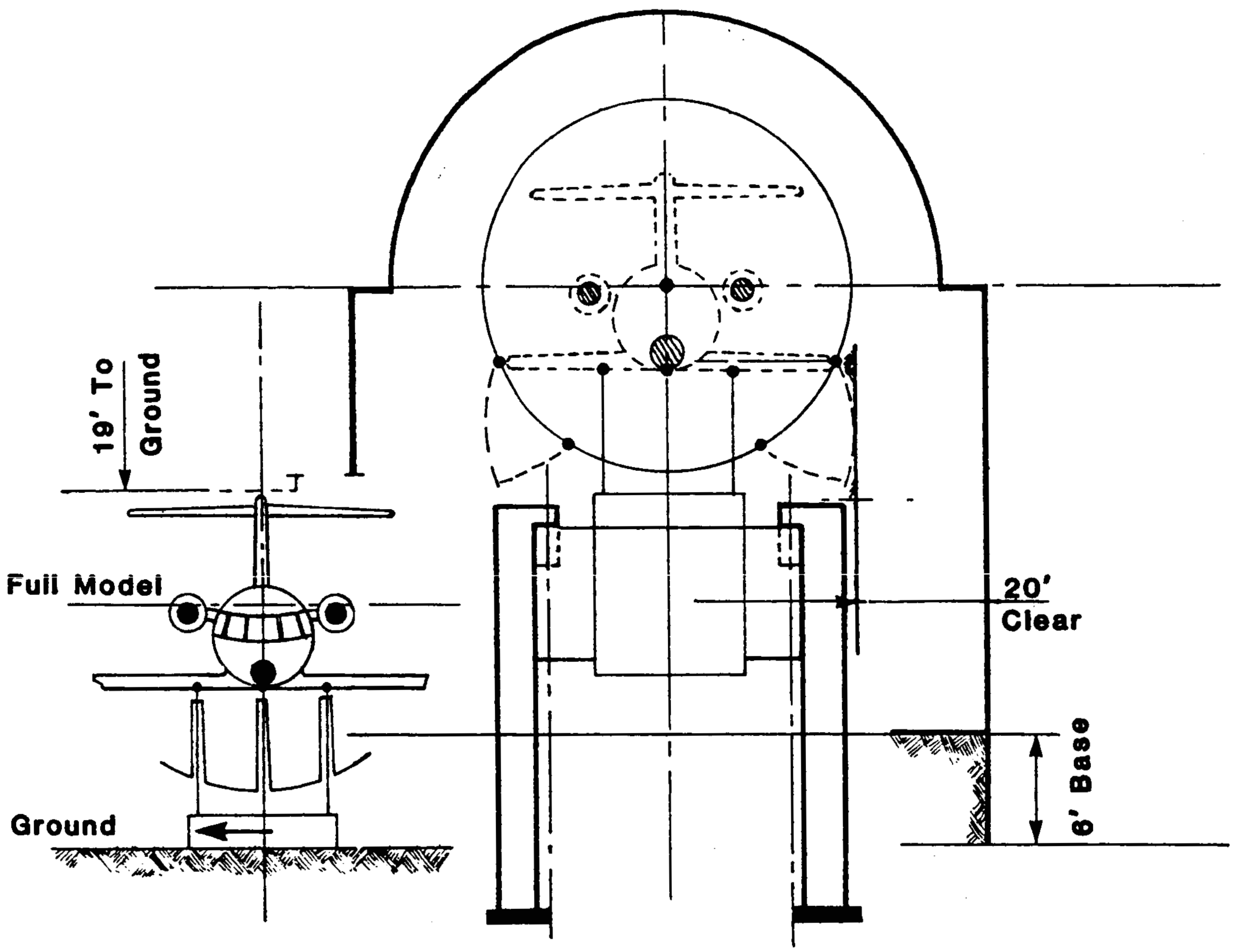


Figure 8 "Long" Platform End View

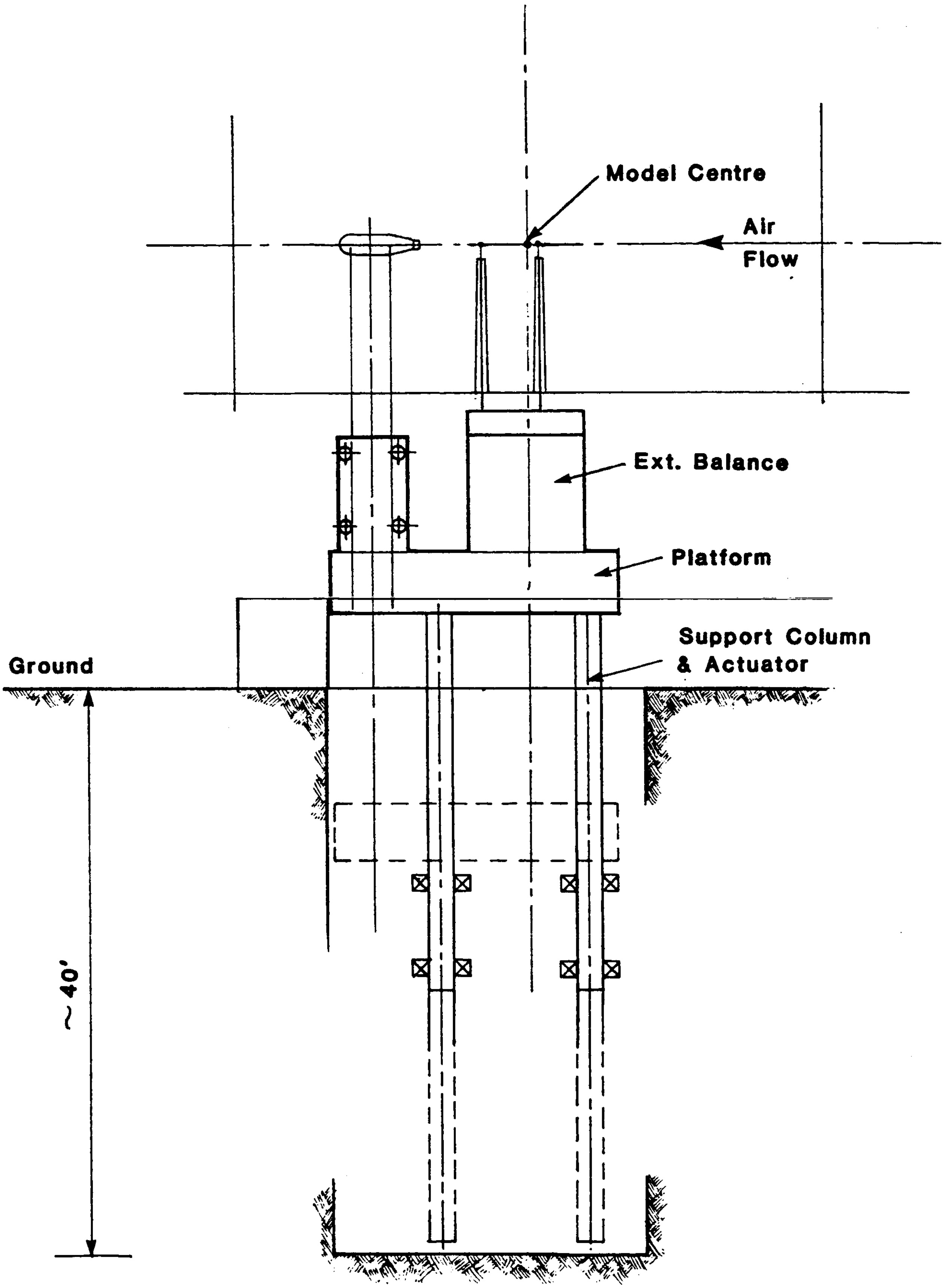


Figure 9 "Short" Platform #1
Elevation View

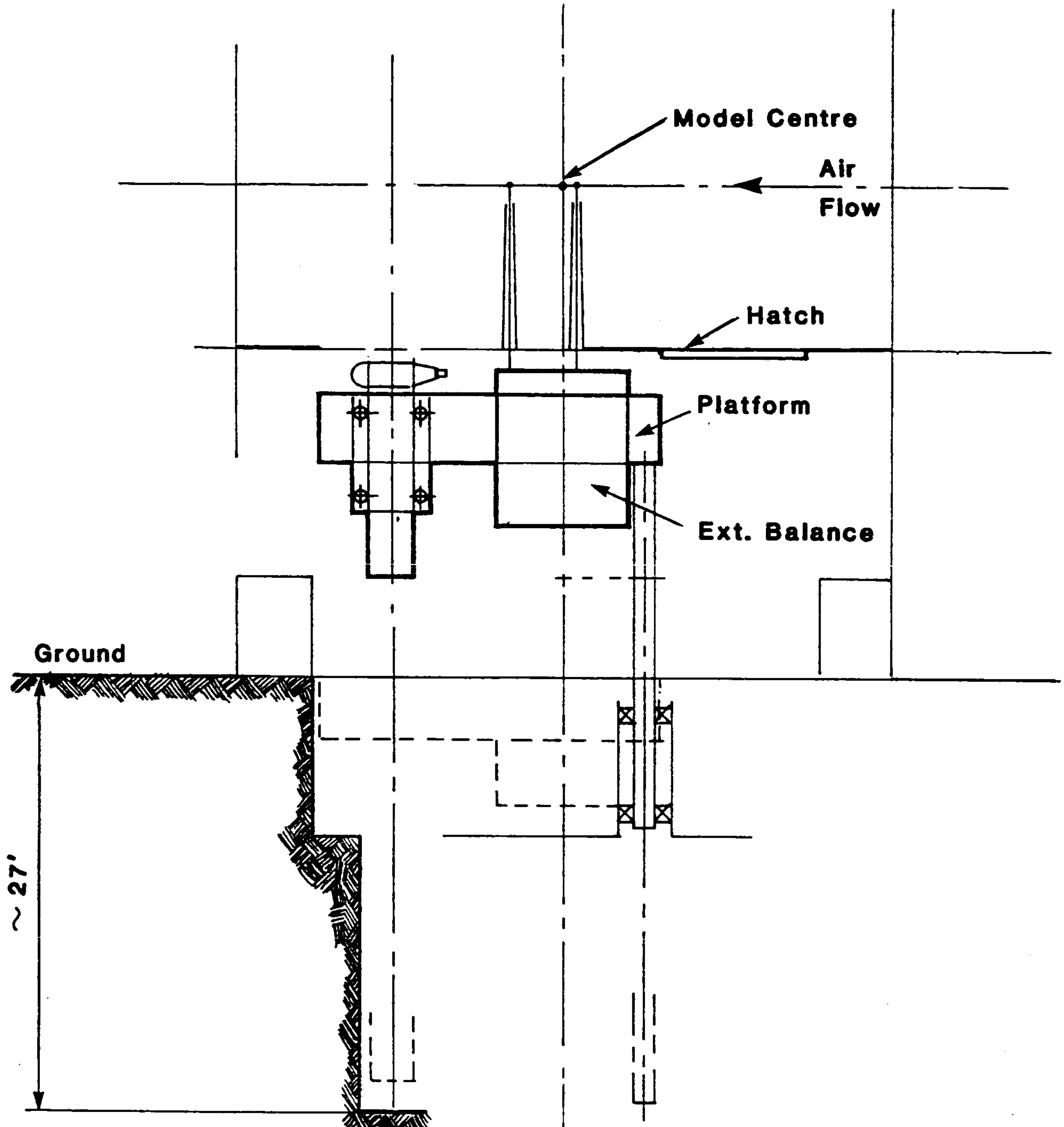
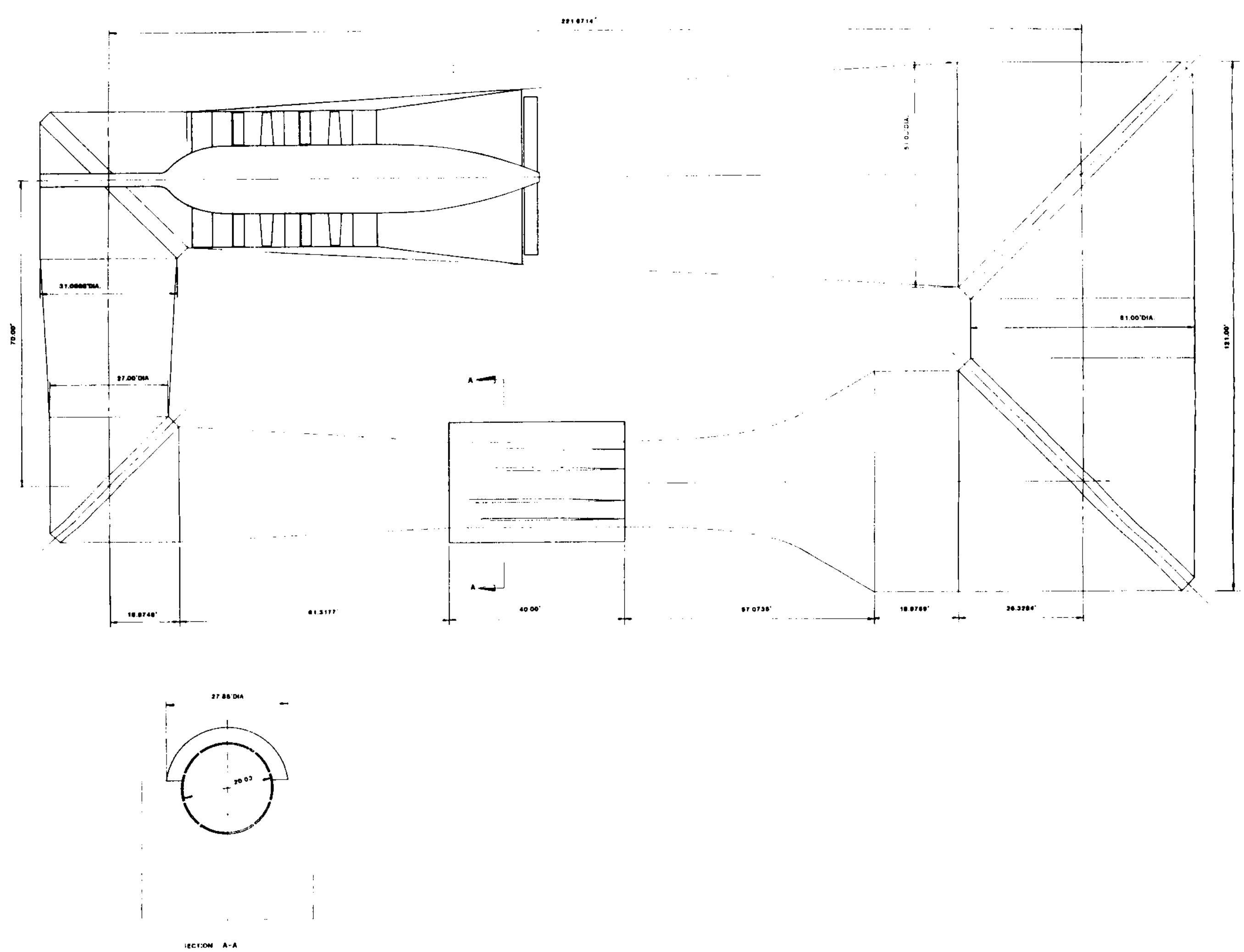


Figure 10 "Short" Platform #2
Elevation View

DRAWINGS

E44532



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LEWIS RESEARCH CENTER
Cleveland, Ohio 44135

ALTITUDE WIND TUNNEL

DSMA Engineering Corporation
Orlando, Florida

DSMA International Inc.
Engineers and Constructors
Toronto, Canada

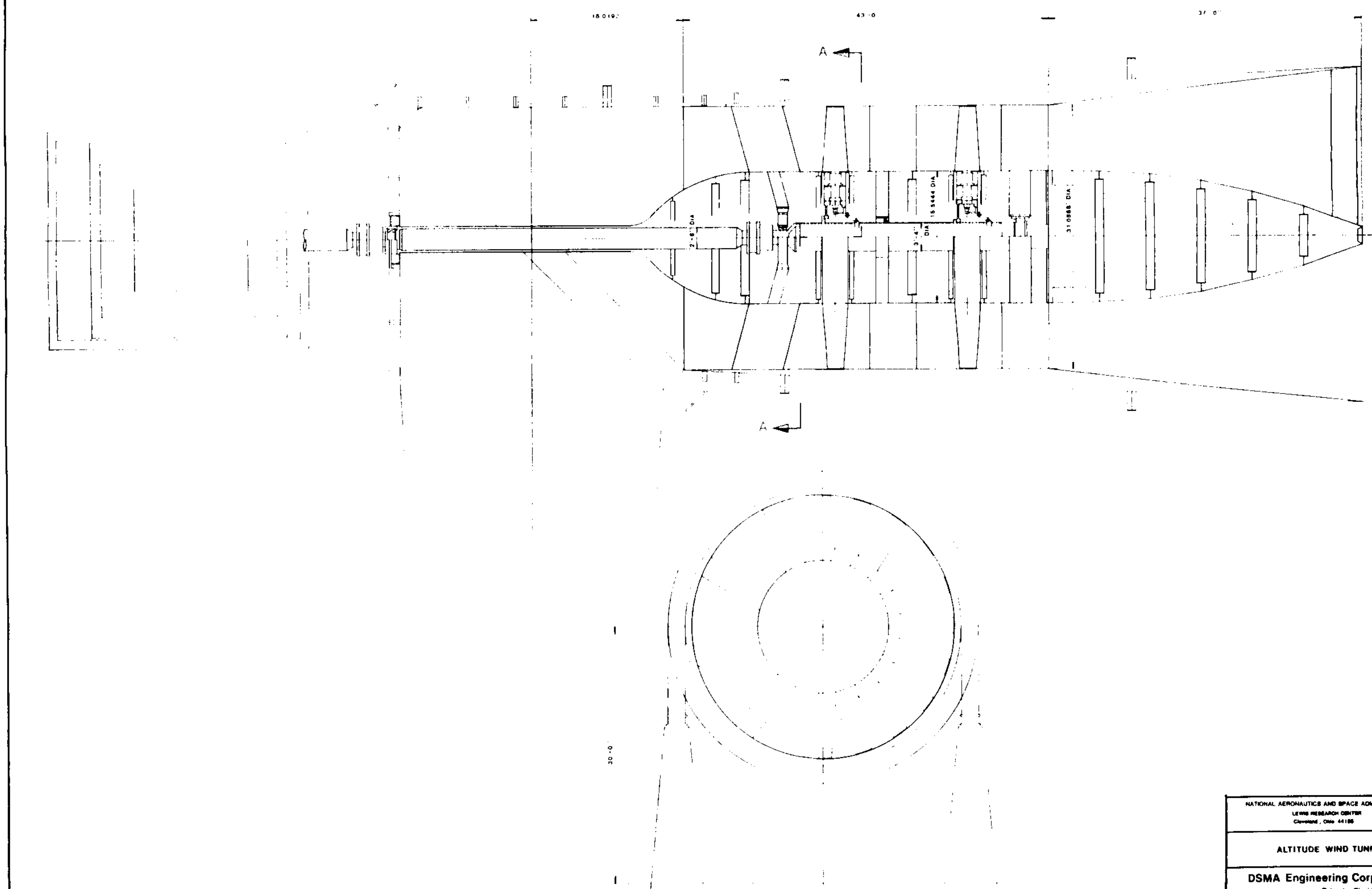
PROPOSED AIRLINE MODIFICATIONS

BJ	MODIFY TS FAN
MH	AS DRAWN
	REVISION

PROJECTION: THIRD ANGLE

PROJECT 4025

DWG. NO. E44532



SECTION A-A 90° ROTATED

DRAWN	R.K.
REVISION	A. DRAWN

FAN CONCEPT
VARIABLE BLADE PITCH
GENERAL ARRANGEMENT

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LEWIS RESEARCH CENTER
Cleveland, Ohio 44135

ALTITUDE WIND TUNNEL

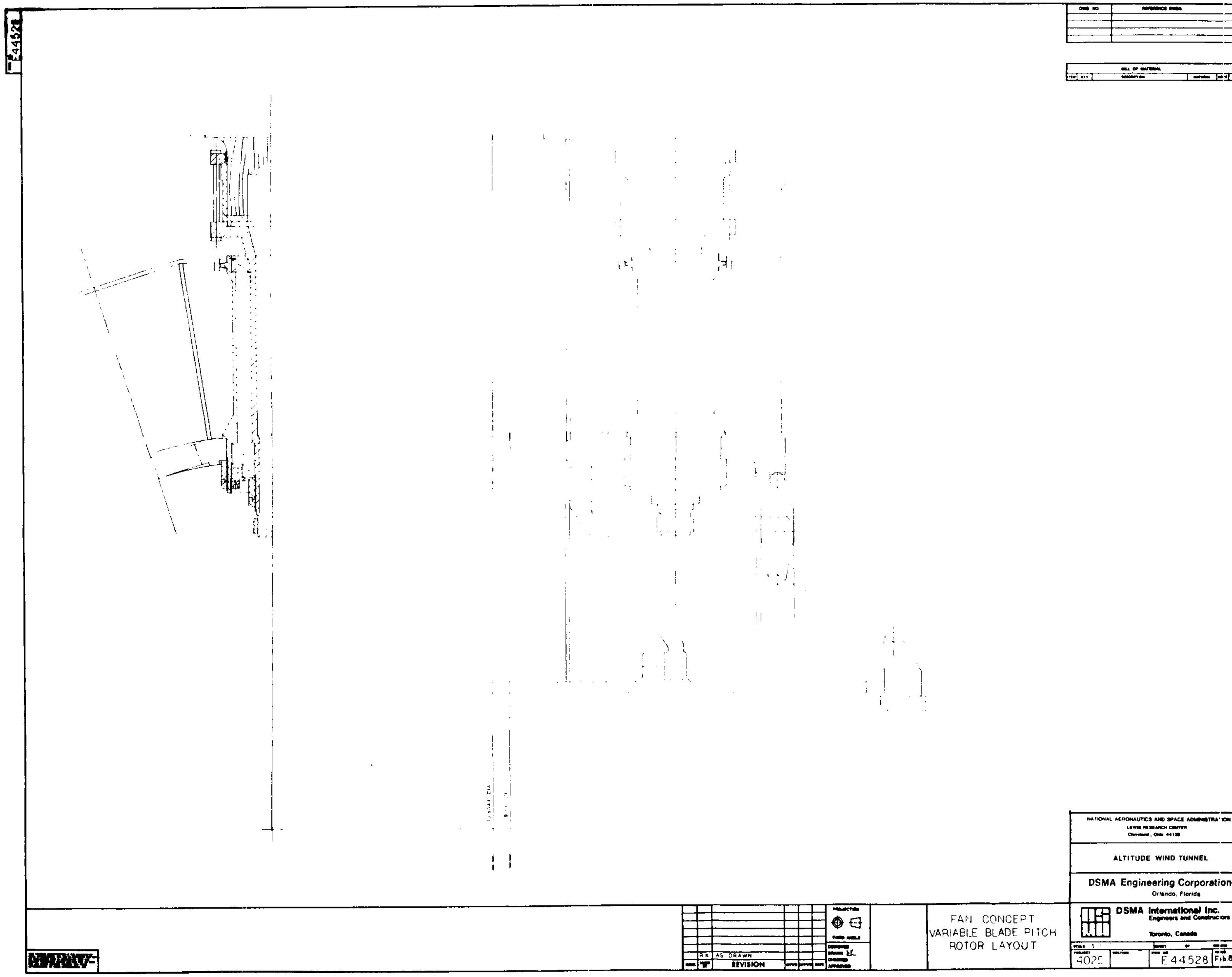
DSMA Engineering Corporation
Orlando, Florida

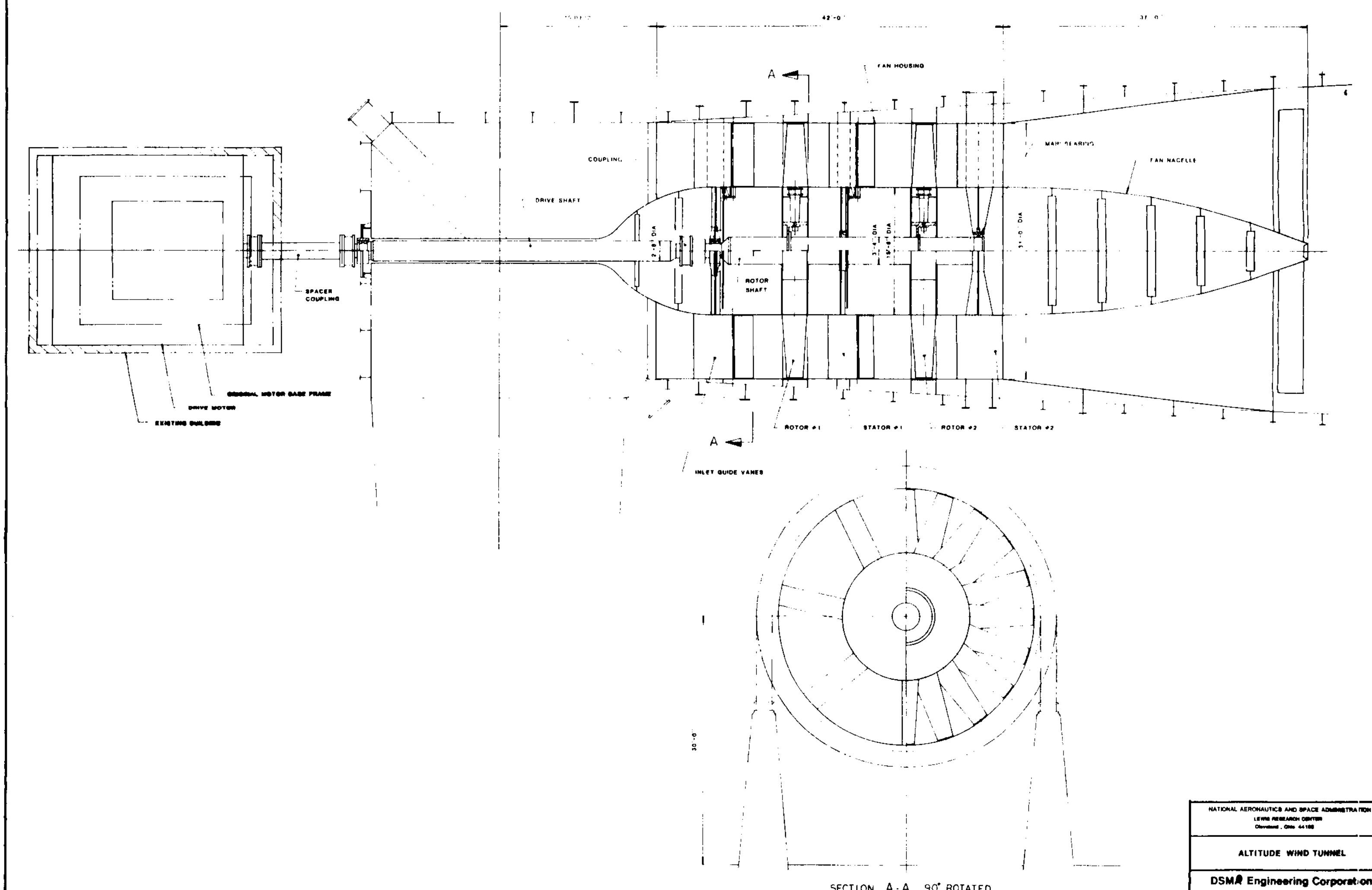
DSMA International Inc.
Engineers and Constructors
Toronto, Canada

Scale 1/4" = 1'-0"

4025

E44527


NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LEWIS RESEARCH CENTER
Cleveland, Ohio 44135
ALTITUDE WIND TUNNEL
DSMA Engineering Corporation
Orlando, Florida
DSMA International Inc.
Engineers and Constructors
Toronto, Canada
FAN CONCEPT
VARIABLE BLADE PITCH
ROTOR LAYOUT
AS DRAWN
REVISION
4025
E44528



R.K.	AS DRAWN		
	REVISION		

FAN CONCEPT
FIXED BLADE PITCH
GENERAL ARANGEMENT

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LEWIS RESEARCH CENTER
Cleveland, Ohio 44135

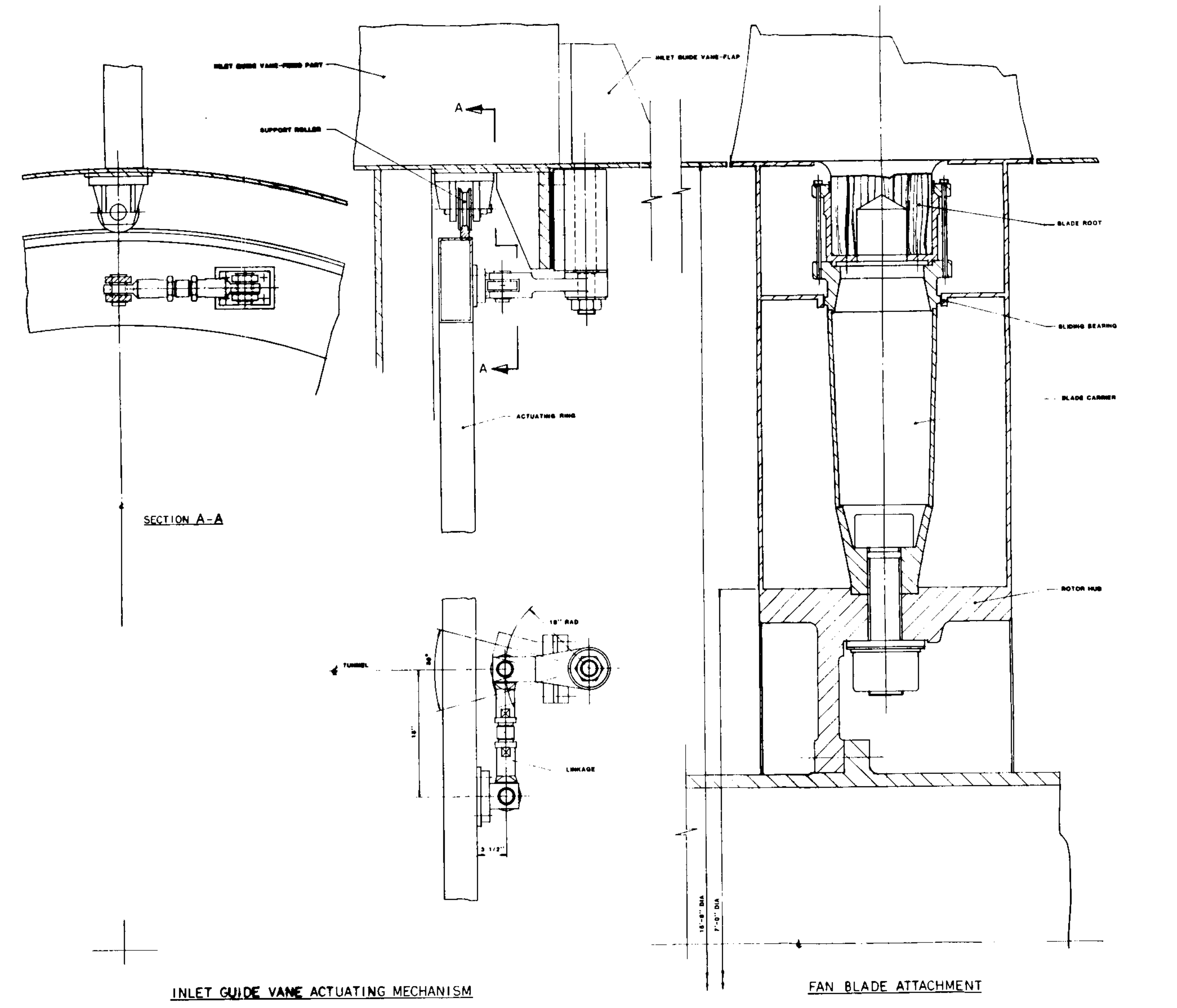
ALTITUDE WIND TUNNEL

DSMA Engineering Corporation
Orlando, Florida

DSMA International Inc.
Engineers and Constructors
Toronto, Canada

Scale 1/8" = 1'-0"

4025 E44529



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LEWIS RESEARCH CENTER
Cleveland, Ohio 44135

ALTITUDE WIND TUNNEL

DSMA Engineering Corporation
Orlando, Florida

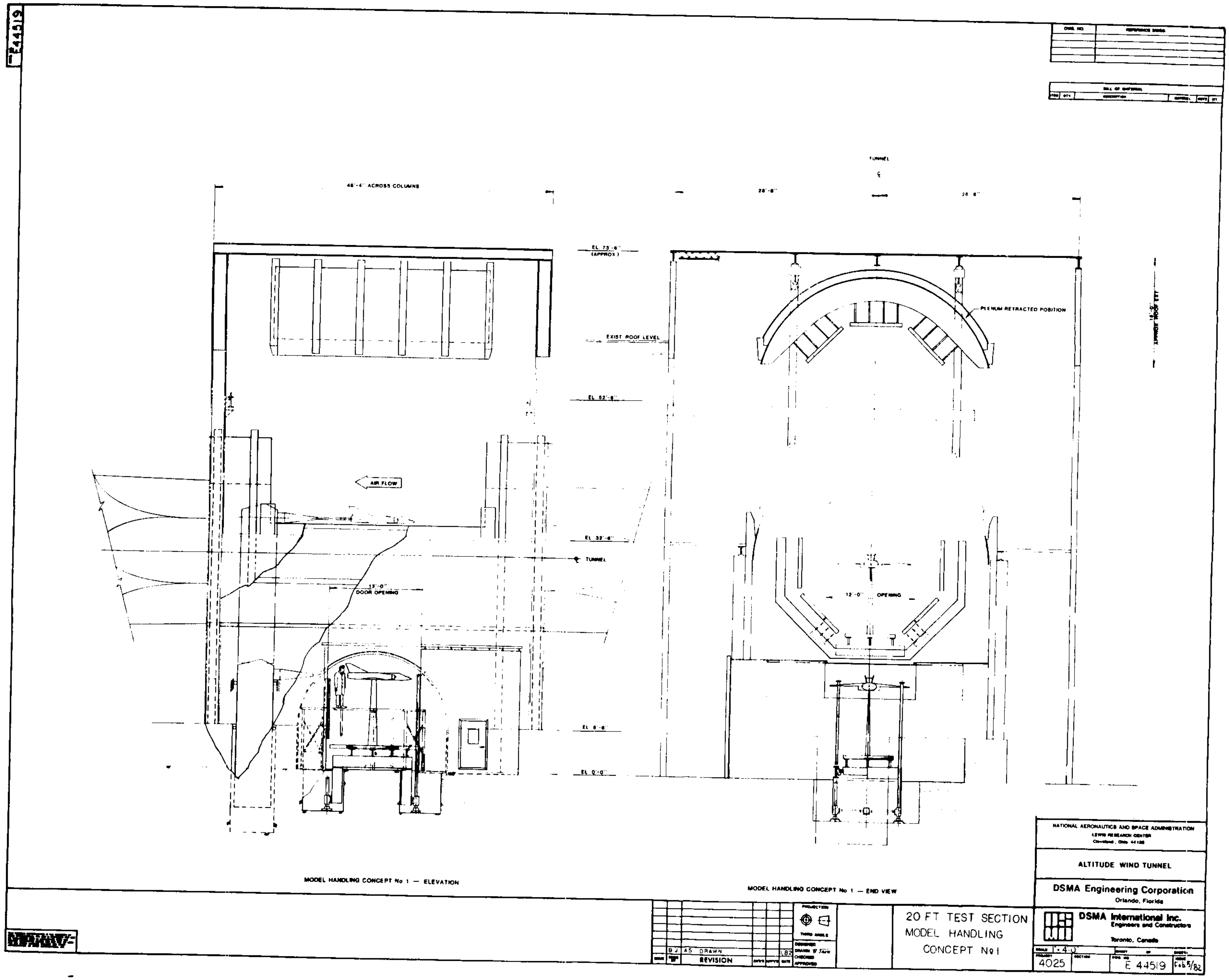
DSMA International Inc.
Engineers and Constructors
Toronto, Canada

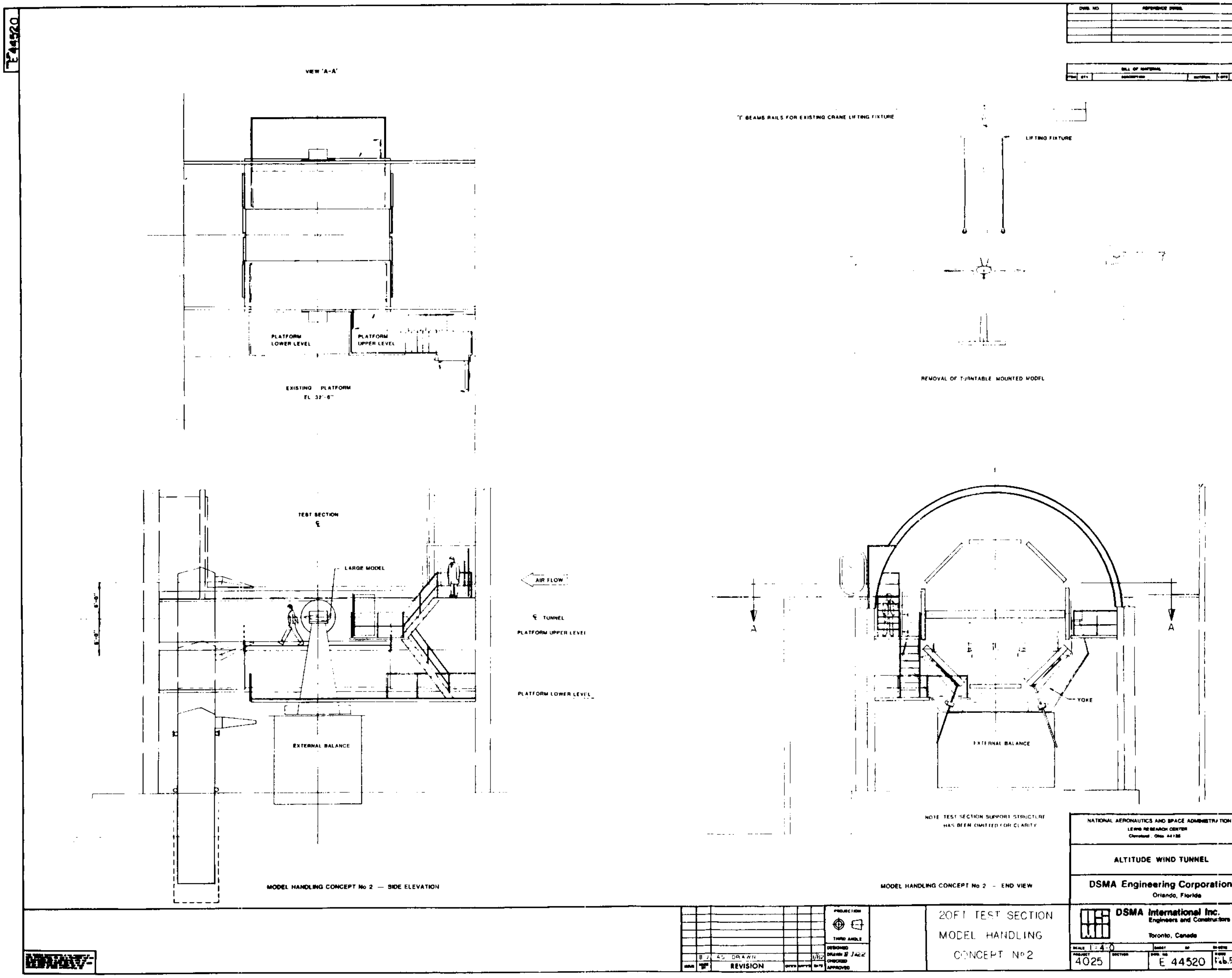
FAN CONCEPT
FIXED BLADE PITCH-ROTOR
& IGV MECHANISM LAYOUT

AS DRAWN
REVISION

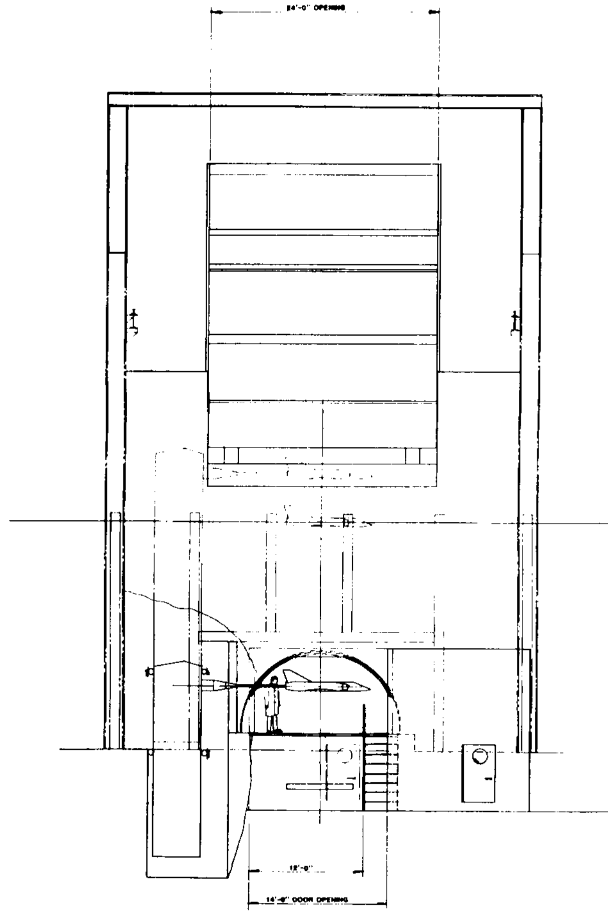
4025
E44530

E44530

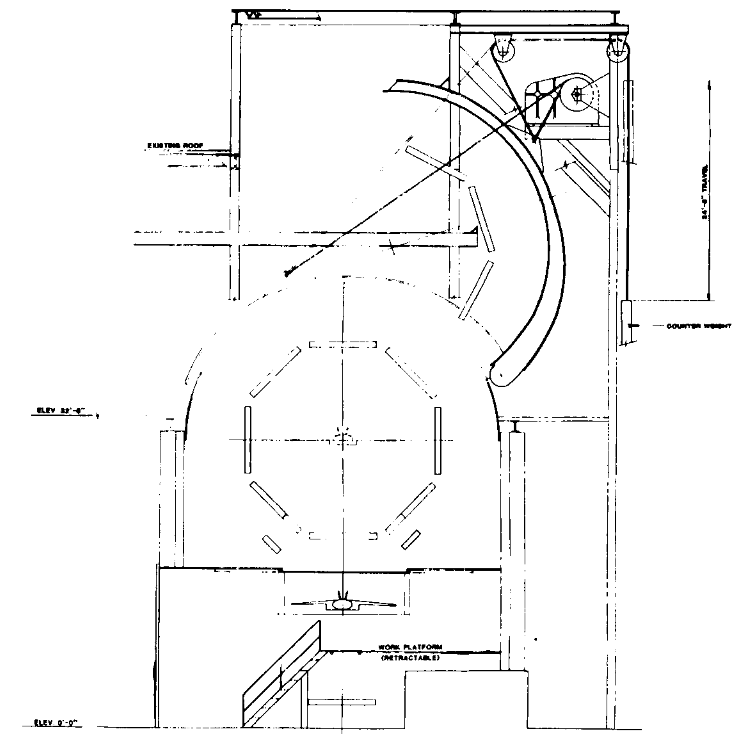

E44519
48'-4" ACROSS COLUMNS
TUNNEL ℄
28'-6"
28'-6"
EL 73'-6" (APPROX.)
EXIST ROOF LEVEL
EL 52'-6"
EL 33'-6"
℄ TUNNEL
EL 8'-6"
EL 0'-0"
AIR FLOW
13'-0" DOOR OPENING
12'-0" OPENING
PLENUM RETRACTED POSITION
18'-0" APPROX ROOF EXT
MODEL HANDLING CONCEPT No 1 — ELEVATION
MODEL HANDLING CONCEPT No 1 — END VIEW
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LEWIS RESEARCH CENTER
Cleveland, Ohio 44135
ALTITUDE WIND TUNNEL
DSMA Engineering Corporation
Orlando, Florida
DSMA International Inc.
Engineers and Constructors
Toronto, Canada
20 FT TEST SECTION
MODEL HANDLING
CONCEPT No I
THIRD ANGLE
AS DRAWN
REVISION
4025
E 44519



E 44520
VIEW 'A-A'
PLATFORM LOWER LEVEL
PLATFORM UPPER LEVEL
EXISTING PLATFORM
EL 32'-6"
'I' BEAMS RAILS FOR EXISTING CRANE LIFTING FIXTURE
LIFTING FIXTURE
REMOVAL OF TURNTABLE MOUNTED MODEL
TEST SECTION ℄
LARGE MODEL
AIR FLOW
℄ TUNNEL
PLATFORM UPPER LEVEL
PLATFORM LOWER LEVEL
EXTERNAL BALANCE
MODEL HANDLING CONCEPT No 2 — SIDE ELEVATION
A
A
YOKE
EXTERNAL BALANCE
NOTE TEST SECTION SUPPORT STRUCTURE HAS BEEN OMITTED FOR CLARITY
MODEL HANDLING CONCEPT No 2 — END VIEW
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LEWIS RESEARCH CENTER
Cleveland Ohio 44135
ALTITUDE WIND TUNNEL
DSMA Engineering Corporation
Orlando, Florida
DSMA International Inc.
Engineers and Constructors
Toronto, Canada
20FT TEST SECTION
MODEL HANDLING
CONCEPT No 2
THIRD ANGLE
B AS DRAWN
REVISION
SCALE 1:4-0
PROJECT 4025
E 44520
Feb 5/81



MODEL HANDLING SWING-OUT PLENUM — ELEVATION



NOTE MOST STRUCTURAL SUPPORTS HAVE BEEN OMITTED FOR CLARITY

MODEL HANDLING SWING-OUT PLENUM — END VIEW

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LEWIS RESEARCH CENTER
Cleveland, Ohio 44135

ALTITUDE WIND TUNNEL

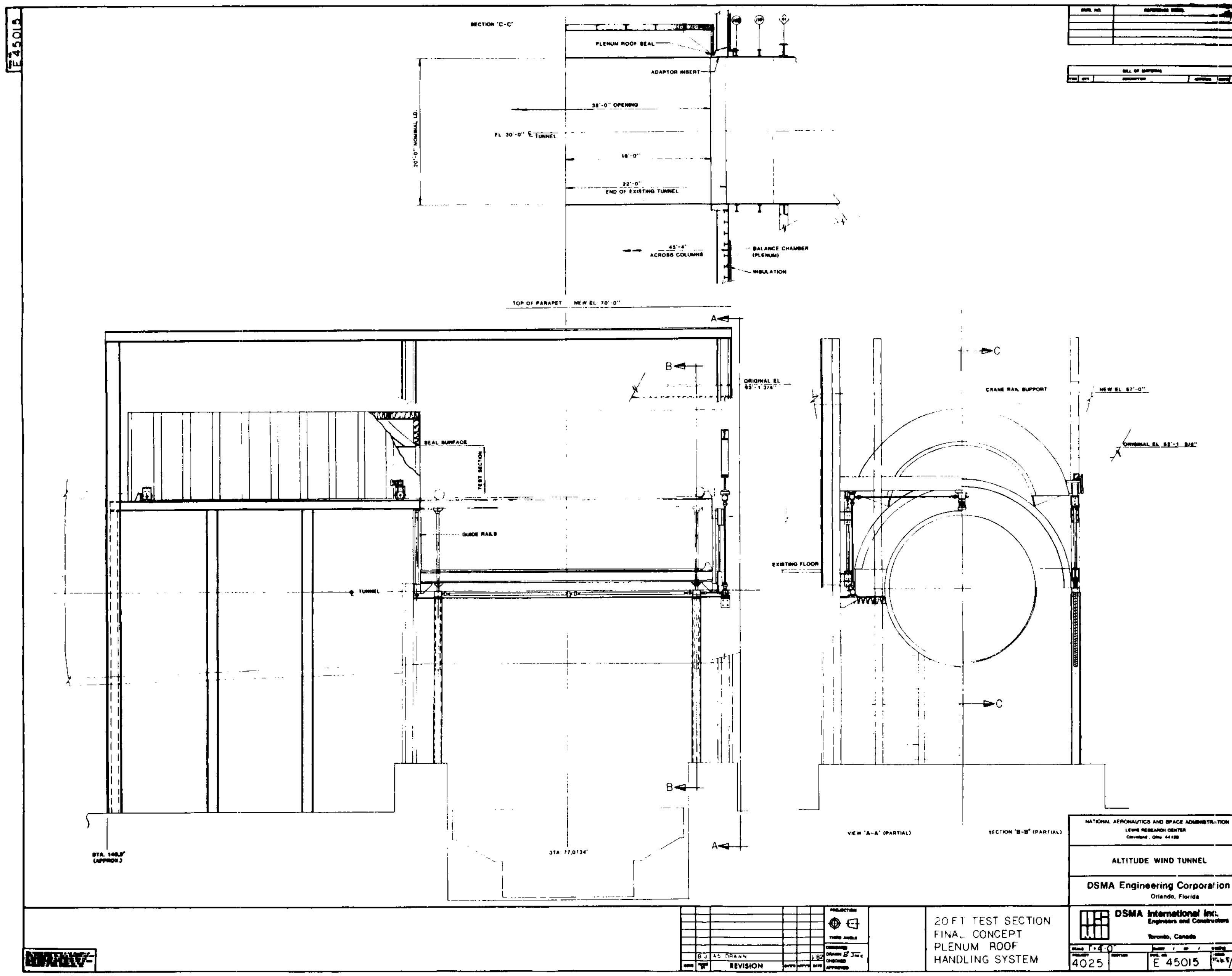
DSMA Engineering Corporation
Orlando, Florida

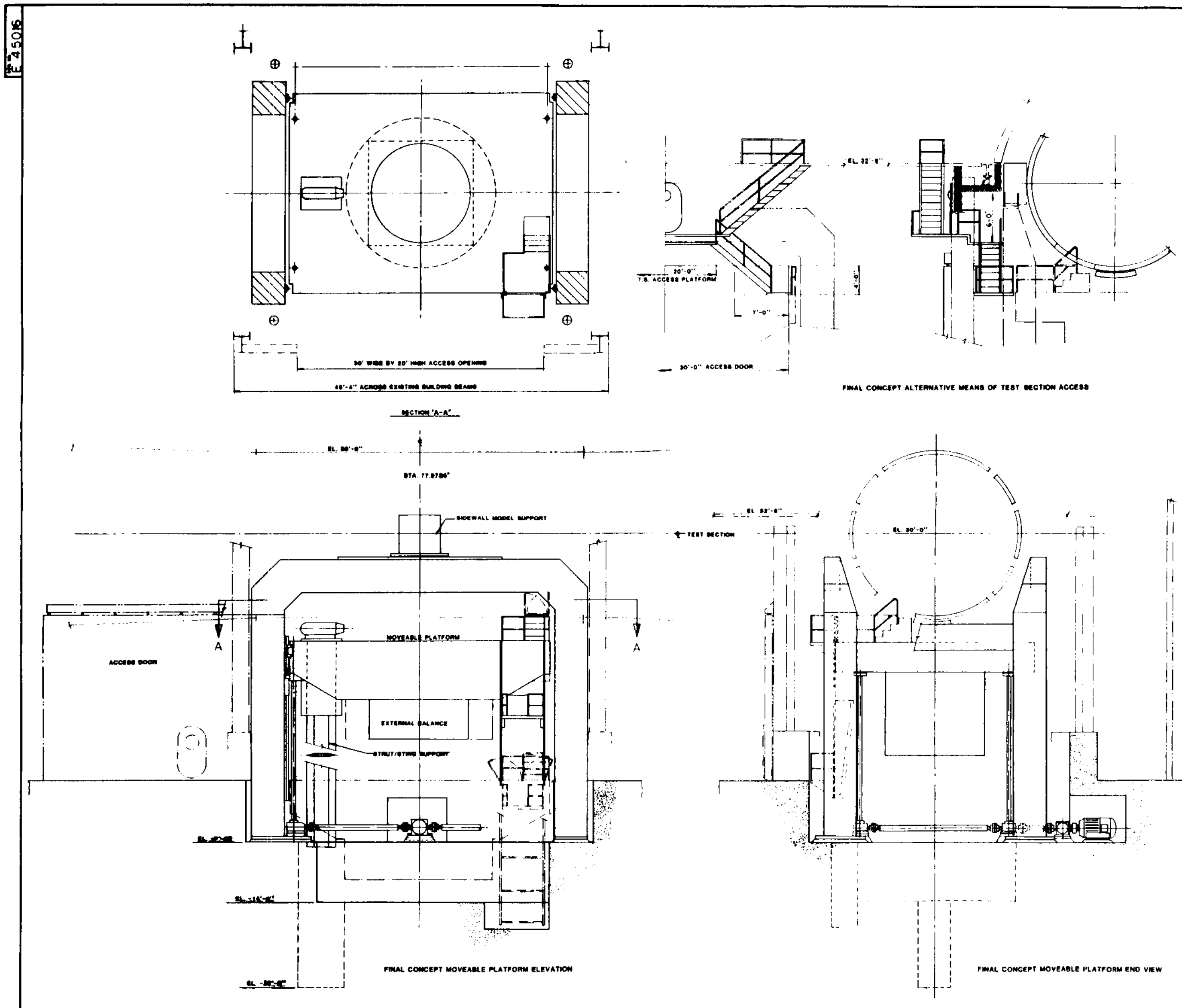
DSMA International Inc.
Engineers and Constructors
Toronto, Canada

20FT TEST SECTION
MODEL HANDLING
SWING-OUT PLENUM

B J | AS DRAWN | 1/82
REVISION

Scale 1"-4'-0"
4025
E 44526
Feb 5/82


E45015
SECTION 'C-C'
PLENUM ROOF SEAL
ADAPTOR INSERT
38'-0" OPENING
FL 30'-0" ℄ TUNNEL
20'-0" NOMINAL I.D.
18'-0"
22'-0"
END OF EXISTING TUNNEL
45'-4"
ACROSS COLUMNS
BALANCE CHAMBER (PLENUM)
INSULATION
TOP OF PARAPET NEW EL 70'-0"
ORIGINAL EL 65'-1 3/4"
SEAL SURFACE
TEST SECTION
GUIDE RAILS
℄ TUNNEL
STA. 146.5' (APPROX.)
STA. 77.0734'
CRANE RAIL SUPPORT
NEW EL 67'-0"
ORIGINAL EL 62'-1 3/4"
EXISTING FLOOR
VIEW 'A-A' (PARTIAL)
SECTION 'B-B' (PARTIAL)
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LEWIS RESEARCH CENTER
Cleveland, Ohio 44135
ALTITUDE WIND TUNNEL
DSMA Engineering Corporation
Orlando, Florida
DSMA International Inc.
Engineers and Constructors
Toronto, Canada
20 FT TEST SECTION
FINAL CONCEPT
PLENUM ROOF
HANDLING SYSTEM
REVISION
AS DRAWN
1"=4'-0"
4025
E 45015



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LEWIS RESEARCH CENTER
Cleveland, Ohio 44135

ALTITUDE WIND TUNNEL

DSMA Engineering Corporation
Orlando, Florida

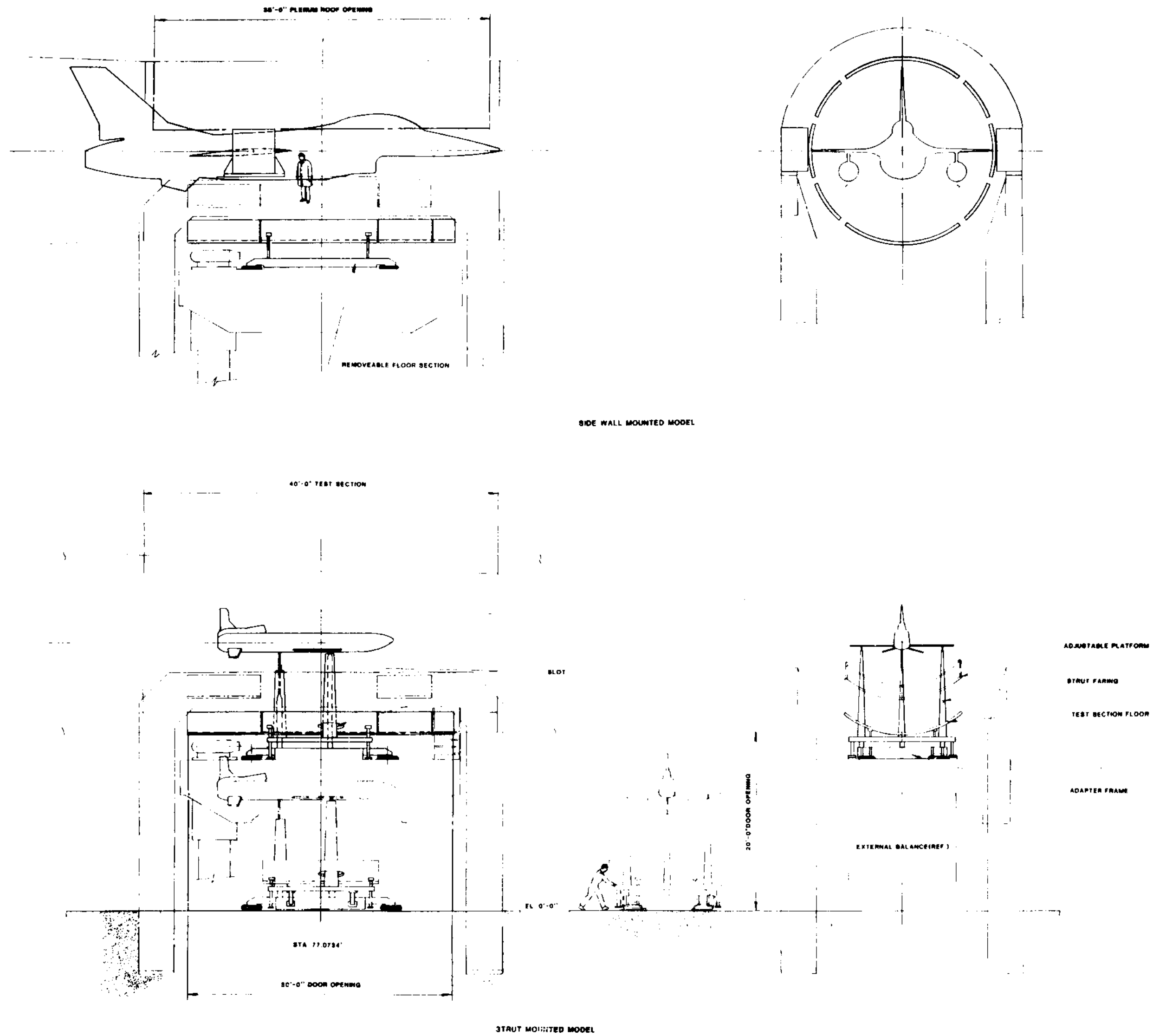
DSMA International Inc.
Engineers and Constructors
Toronto, Canada

20 FT TEST SECTION
FINAL CONCEPT
MOVEABLE PLATFORM
AND TEST SECTION
ACCESS

4025	E45016	Feb 5/82

BJ AS DRAWN 1/82
REVISION

E45016



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LEWIS RESEARCH CENTER
Cleveland, Ohio 44135

ALTITUDE WIND TUNNEL

DSMA Engineering Corporation
Orlando, Florida

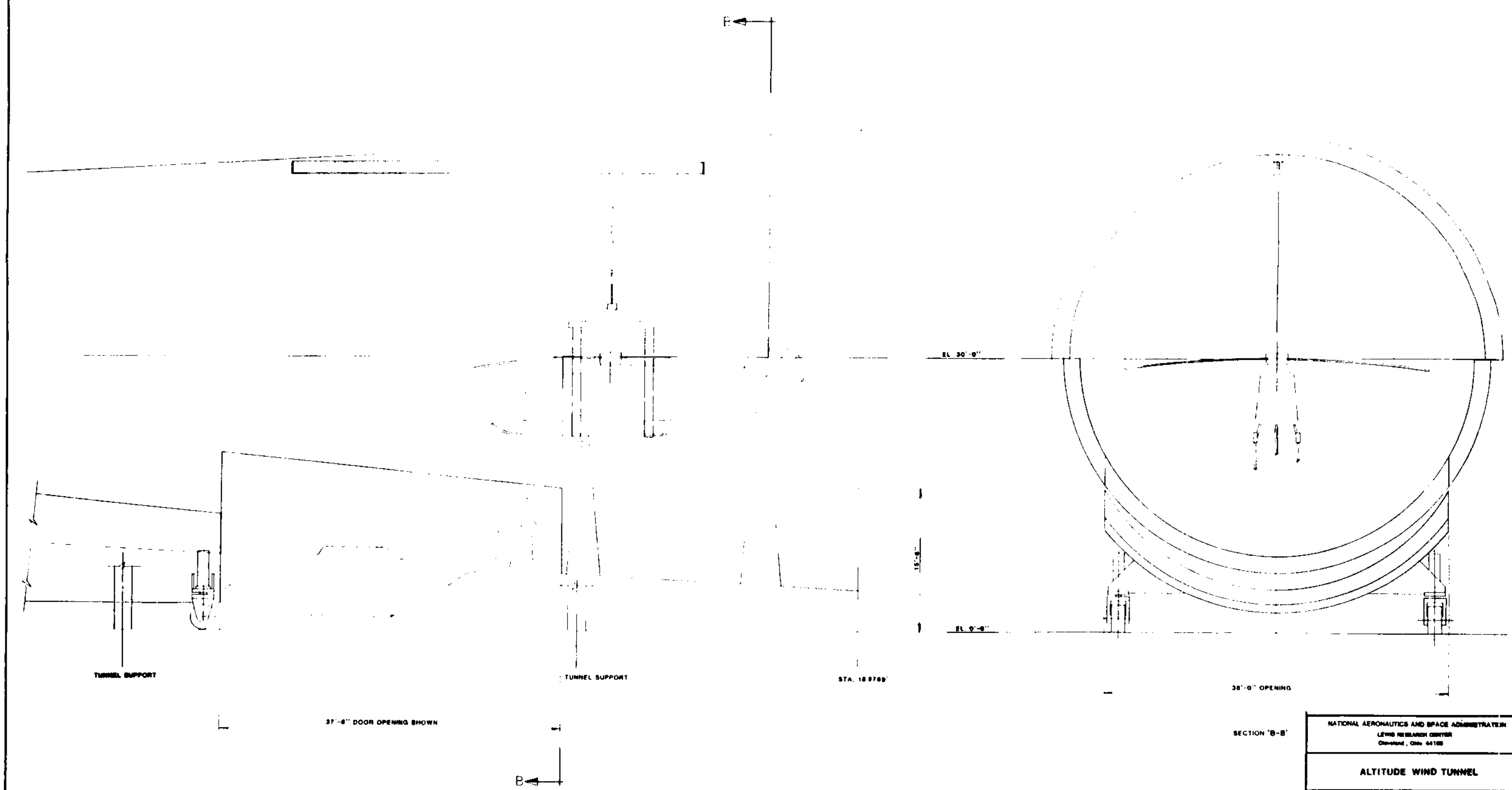
DSMA International Inc.
Engineers and Constructors
Toronto, Canada

20FT TEST SECTION
FINAL CONCEPT
MODEL HANDLING SYSTEM

Scale: 1"=4'-0"
Project: 4025
Dwg. No.: E45017

B | J | AS DRAWN
REVISION

E45017



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LEWIS RESEARCH CENTER
Cleveland, Ohio 44135

ALTITUDE WIND TUNNEL

DSMA Engineering Corporation
Orlando, Florida

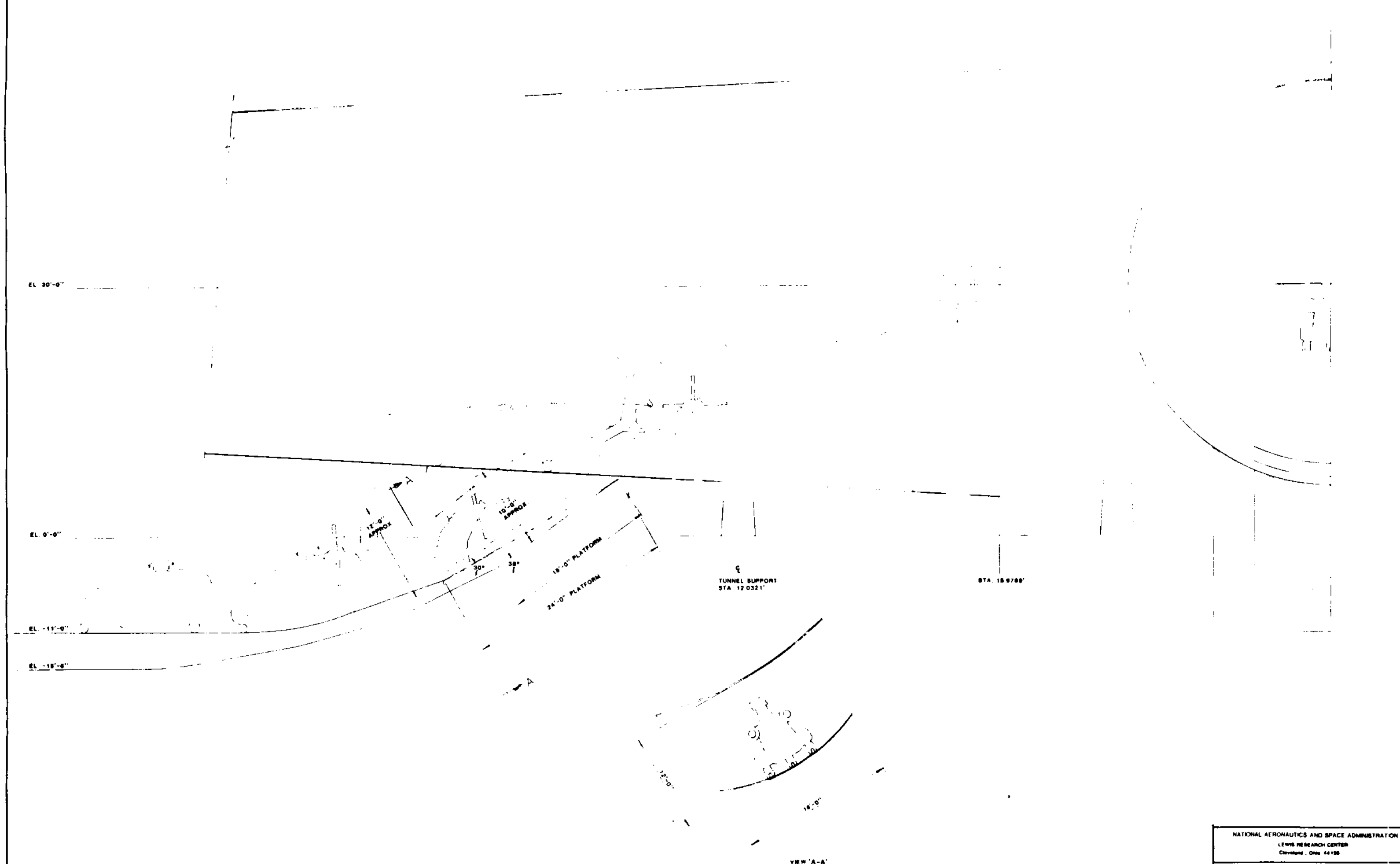
DSMA International Inc.
Engineers and Constructors
Toronto, Canada

45 FT TEST SECTION
MODEL INSTALLATION
CONCEPT No 1

B.J. AS DRAWN — REVISION

Drawn: B. Jack
Scale: 1"=4'-0"
Project: 4025
Dwg. No.: E 44531

E44531



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LEWIS RESEARCH CENTER
Cleveland, Ohio 44135

ALTITUDE WIND TUNNEL

DSMA Engineering Corporation
Orlando, Florida

DSMA International Inc.
Engineers and Constructors
Toronto, Canada

45FT TEST SECTION
MODEL INSTALLATION
CONCEPT No 2

PROJECT	SECTION	DWG NO	ISSUE
4025		E45018	

REVISION

PROJECTION — THIRD ANGLE
DESIGNED
DRAWN
CHECKED
APPROVED