An Improved Propulsion System Simulation Technique for Scaled Wind Tunnel Model Testing of Advanced Fighters

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Abstract

The demanding performance requirements of advanced turbine-powered fighter aircraft may lead to highly-integrated and closely-coupled propulsion systems. These characteristics could result in not only mutual interactions between the inlet and nozzle flowfields, but also flow interactions between the propulsion system and aerodynamic surfaces such as the wing, tails, or canards. It therefore becomes a necessity to be able to understand and accurately evaluate such interactions.

Current wind tunnel model testing techniques cannot accurately account for such interactions, since they do not provide the simultaneous simulation of the inlet, airframe, and nozzle flowfields. However, the development of the supersonic propulsion simulator has been accomplished to eliminate this potential source of error in aircraft performance predictions. The simulator is a flexible cycle miniature engine incorporating a four-stage axial flow compressor driven by a single stage turbine, which is powered by an external source of high pressure air. It thus represents a new scaled-model test tool for use in advanced fighter aircraft development. The primary application for these simulators would be on those advanced aircraft configurations where there exists a strong potential for interactions between the aerodynamic and propulsion system flowfields.

Nomenclature

A_8	Nozzle throat area
A_{e57}	Mixer discharge area
BPR	Engine Bypass Ratio
EPR	Engine Pressure Ratio (P_{T7}/P_{T2})
ES	Engine Station
P_{T2}	Compressor inlet total pressure
P_{T7}	Nozzle entrance total pressure

Introduction

The design and development of advanced supersonic fighter aircraft has, in recent years, included the use of multiple scaled wind tunnel models to determine the basic aerodynamic and propulsion system-related performance characteristics. The two most widely used model concepts are depicted in Figure 1. The first concept, generally referred to as a "flow-through" model, has been used traditionally to obtain basic aerodynamic force and moment data. The correct inlet geometry and flow characteristics are normally simulated in this model concept, with the flow being controlled by either mass flow chokes or calibrated plugs located at the rear of the "engine" duct. However, because of the geometry of these chokes and the low total pressure of the incoming flow, there is generally no correct simulation of the engine nozzle geometry or exhaust plume characteristics.

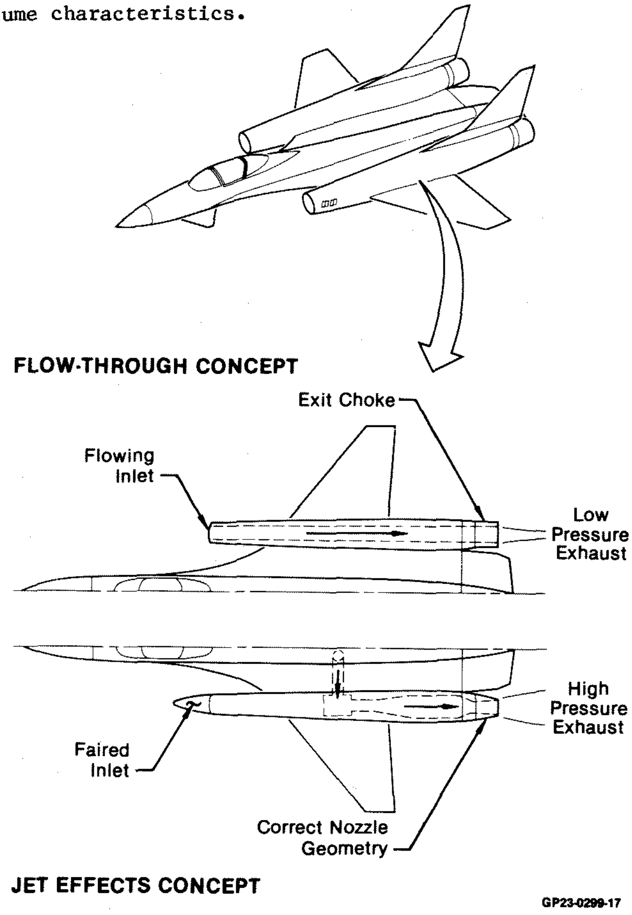

Figure 1. Conventional Wind Tunnel Model Concepts for Performance Prediction

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The second model concept, generally referred to as a "jet effects" model, is therefore subsequently used to correct the basic aerodynamic force and moment data for the effects of correctly simulated engine nozzle geometry and exhaust plume characteristics. The required high pressure exhaust nozzle air for this model is supplied through the model support system from an outside source. With this concept, the inlet duct is either faired over or blocked off, with all normal inlet flow being spilled around the fuselage. As a result, there is no correct simulation of the inlet geometry or incoming streamtube characteristics.

Data obtained with these models is usually systematically combined with other data to predict the overall aircraft performance. A typical thrust/drag accounting system employing these and two other scale model concepts is schematically shown in Figure 2 for a conventional fighter-type aircraft. A sting-supported flow-through model is used to obtain the basic aerodynamic forces and moments, as well as the force and moment increments due to inlet flow changes. A strut-supported flow-through model provides support system corrections to this basic data. A strut-supported jet effects model provides the aerodynamic force and moment increments due to nozzle geometry and exhaust flow changes. Finally, a separate inlet performance model is used to obtain internal inlet recovery and distortion characteristics. This data, when combined with the engine manufacturer-supplied thrust and fuel flow data, provide an overall estimate of the aircraft performance capabilities.

The one major drawback with flow-through and jet-effects model concepts is that they do not provide for the simultaneous simulation of the complete inlet/nozzle geometries and corresponding flowfield characteristics on a single scaled wind tunnel model. The effects of any inlet/airframe/nozzle flowfield interactions are therefore not accounted for in the resultant aircraft performance predictions. It can be argued that this simultaneous simulation is not required since such flowfield interactions are not significant. However, since the experimental capability to isolate and evaluate the impact of these interactions on fighter-type aircraft has not existed, any postulation as to the significance of such interactions is without foundation.

The presence of inlet/airframe/nozzle flowfield interactions on an advanced fighter aircraft design is certainly difficult to forecast. However, there are certain characteristics associated with new emerging technology advancements in the propulsion system area that, if employed in the next fighter, would imply a strong potential for such interactions. As illustrated in Figure 3, advanced propulsion system components such as axisymmetric or two-dimensional thrust reversing/vectoring nozzles, short offset diffusers and top-mounted inlets could very well be included in the next advanced supersonic fighter design. When such components are integrated with advanced aerodynamic features, the overall aircraft design could evolve with closely-coupled propulsion system and aerodynamic elements, and resultant inlet/airframe/nozzle flowfield interactions. Such interactions might exist at representative cruise and maneuvering type flight conditions, as well as short takeoff/landing (i.e., STOL) conditions.

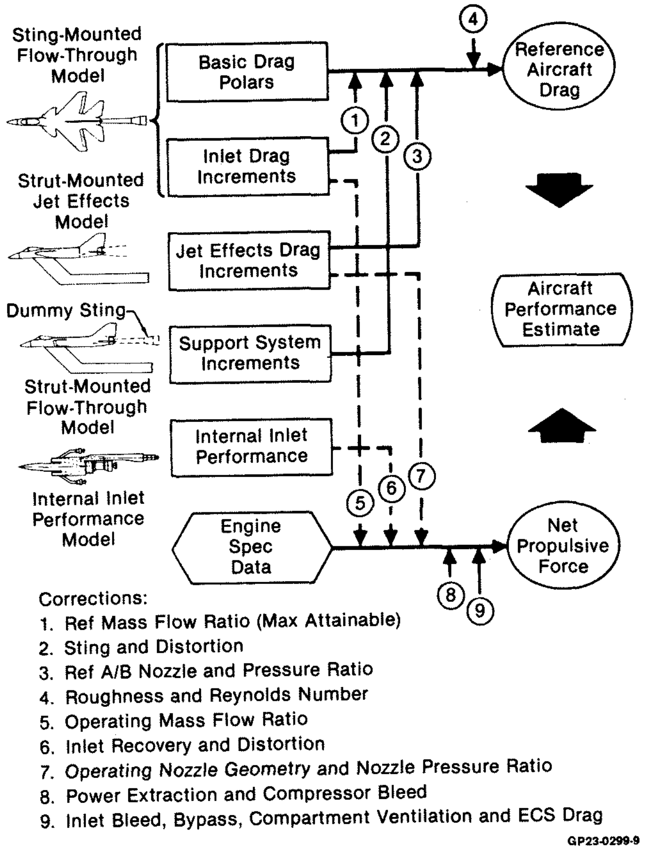


Figure 2. Typical Aircraft Thrust/Drag Accounting System Using Conventional Models

This paper traces the development of the supersonic propulsion simulator as a test tool to provide complete propulsion system simulation on a single scaled wind tunnel model. The discussion includes the simulator performance characteristics, engine cycle simulation capability, general wind tunnel model installation considerations, possible thrust/drag accounting systems, and potential usage in a fighter aircraft development program.

Supersonic Propulsion Simulator Development

Since 1969, the United States Air Force Aero Propulsion Laboratory has sponsored[1,2,3,4,5,6] the development of supersonic propulsion simulators as a means of providing the simultaneous simulation of inlet/airframe/nozzle geometries and flowfields on a single scaled wind tunnel model. The current simulator design, Figure 4, represents the culmination of that development, which has involved the efforts of McDonnell Aircraft Company, General Electric Company, and Tech Development, Inc. This simulator incorporates a four-stage axial compressor and single-stage turbine supported on two main bearings, drive and bleed air manifolds, and flow mixer. The energy for powering the turbine is supplied from an external source of high pressure air.

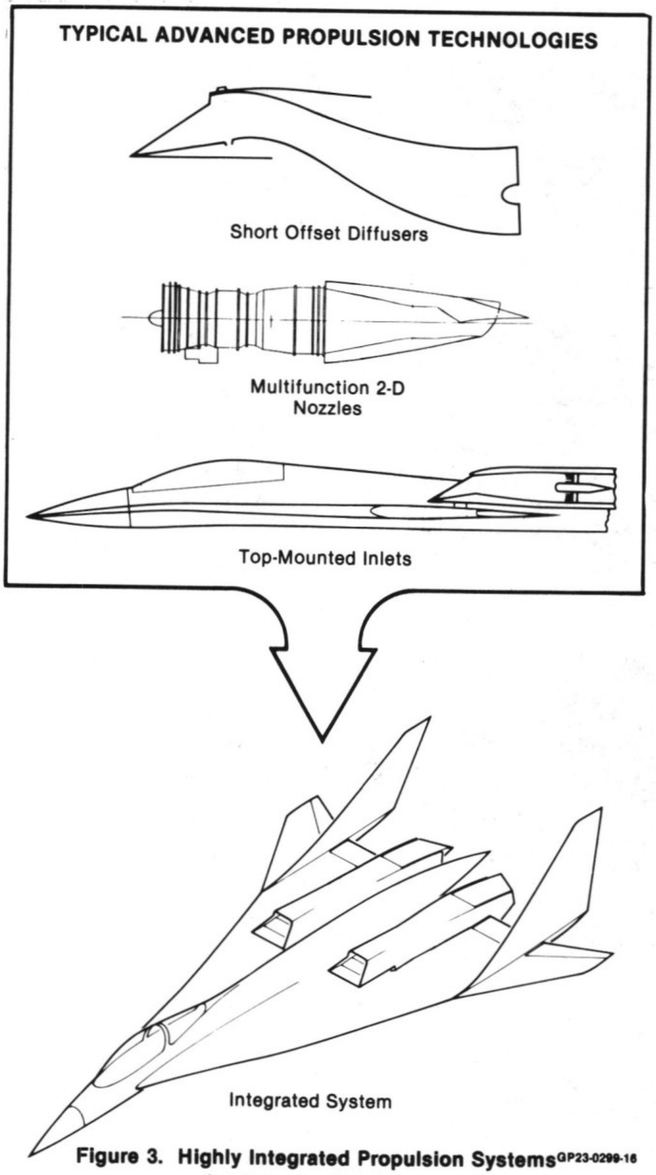
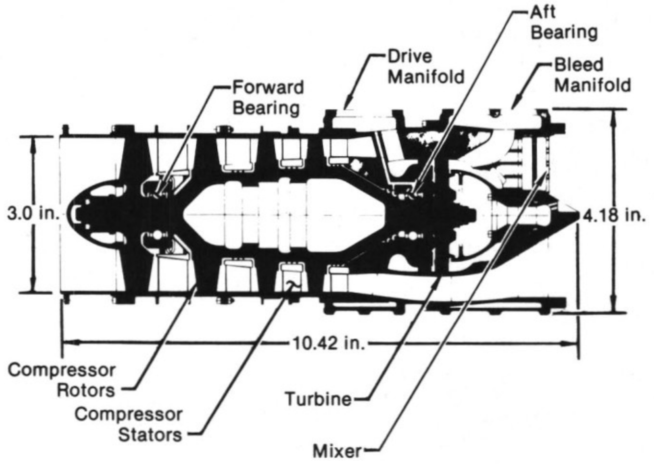


Figure 3. Highly Integrated Propulsion Systems for Advanced Fighters GP23-0299-16



Design Characteristics

- Design Corrected Speed - 75,185 rpm
- Max Physical Speed - 88,600 rpm
- Design Corrected Compressor Airflow - 1.554 lb/sec
- Max Compressor Discharge Temperature - 500°F
- Max Turbine Inlet Pressure - 1,500 psia
- Mixer Pressure Limit - 650 psia

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Figure 4. Supersonic Simulator Schematic

The simulator unit, without nozzles, has an overall length of 10.4 inches, maximum diameter of 4.2 inches, and inlet flowpath diameter of 3.0 inches. The approximate weight is 17 pounds. The compact size of the unit is made possible through the use of numerous thin-walled castings in many of the hardware components, as shown in Figure 5. The complex flow passages inside critical components, including mainframe, bleedframe, and mixers, preclude the effective use of more conventionally-machined hardware.

It was recognized early in the simulator development that future testing of scaled wind tunnel models employing these devices would be a complex task, since the simulator has many of the operational and control requirements of a full scale engine. Therefore, concurrent with the development of the simulator, a digital control console system was also developed. This control system, schematically illustrated in Figure 6, provides for both manual and automatic control of two simulators. Automatic warning and shutwown features associated with major health and operational parameters are also included. It is anticipated that with the digital control system, the testing of simulator-equipped wind tunnel models can be accomplished efficiently, with data acquisition rates comparable to more conventional jet effects models.

Through 1981, a total of 234 powered hours of operation (rotor speed of 35,000 RPM or greater) had been accumulated on various supersonic propulsion simulator units. Forty-eight of these powered hours were accumulated in a wind tunnel operational environment, being tested in a partial F-15 model at speeds up to 1.2 Mach number.[5] In addition, 55 powered hours were accumulated on the current simulator design, all at static test conditions.[7] Two new programs[8,9] sponsored by the Air Force and NASA-Ames will accumulate additional powered hours of operation, as well as provide the first evaluations of the simulator installed in realistic scaled fighter aircraft wing tunnel models.

Simulator Performance Flexibility

Ultimately, the usefulness of the supersonic propulsion simulator in scaled wind tunnel model testing will be dependent on its performance flexibility. This flexibility is defined as the capability to vary either compressor airflow or engine pressure ratio (EPR) while holding the other parameter fixed. It is this flexibility that gives the simulator the ability to match the scaled airflow and EPR characteristics of a variety of modern and advanced engine cycles, typical of those currently used or being considered for the next generation fighter.

In a wind tunnel model installation, the simulator can always be made to match the actual engine cycle airflow characteristics through proper scaling of the model. In general, the model scale should be established as follows:

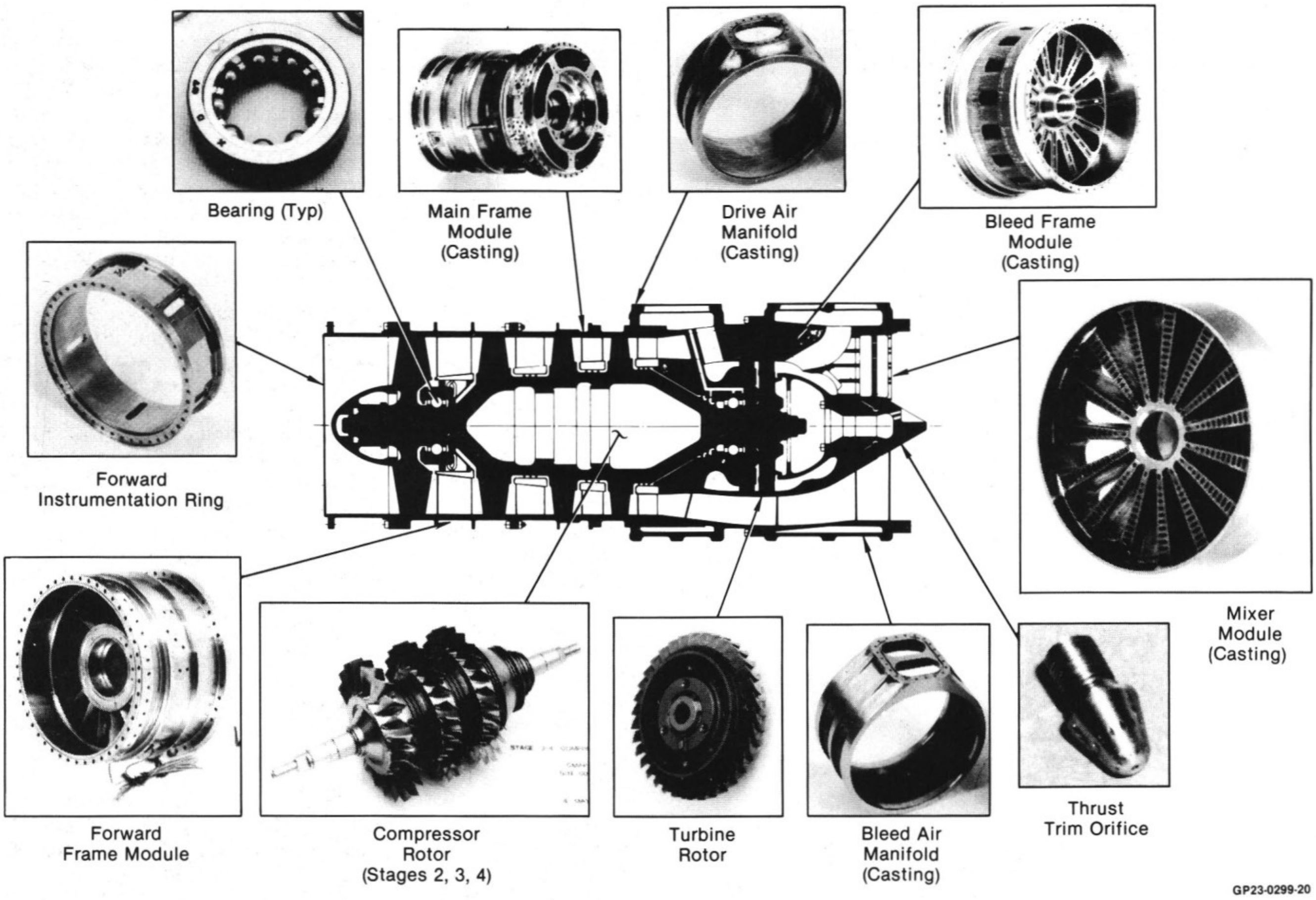


Figure 5. Supersonic Simulator Hardware Components

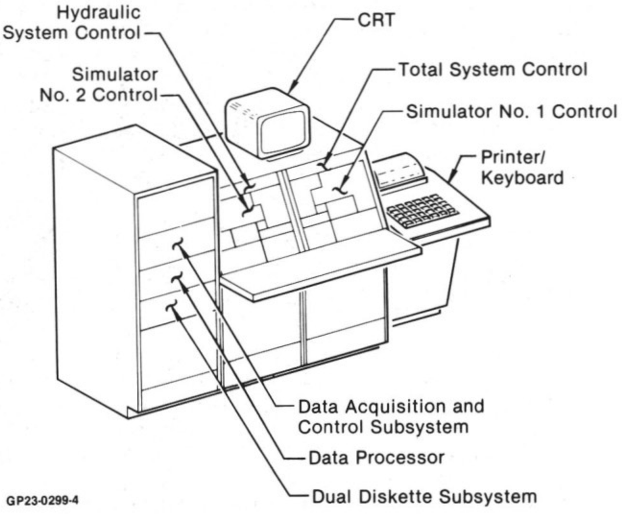


Figure 6. Supersonic Simulator Digital Control System

$$\text{Scale} = \sqrt{\frac{\text{Simulator Maximum Compressor Corrected Airflow}}{\text{Engine Maximum Compressor Corrected Airflow}}}$$

Using the above scaling equation, combined with the maximum airflow capability of the simulator (1.65 lb/sec), results generally in an 8% to 11% scale model for a typical advanced fighter aircraft.

The matching of the actual engine EPR characteristics is, however, dependent on factors other than simple scaling. The capability of the simulator to vary EPR at a fixed compressor airflow is provided by directing all or part of the turbine discharge airflow through the mixer to combine with the compressor flow, as illustrated in Figure 7. Any turbine discharge airflow not directed through the mixer is routed out of the simulator through a separate bleed air line. The amount of turbine discharge air split between the mixer and bleed air line is controlled by a valve located remote in the bleed line.

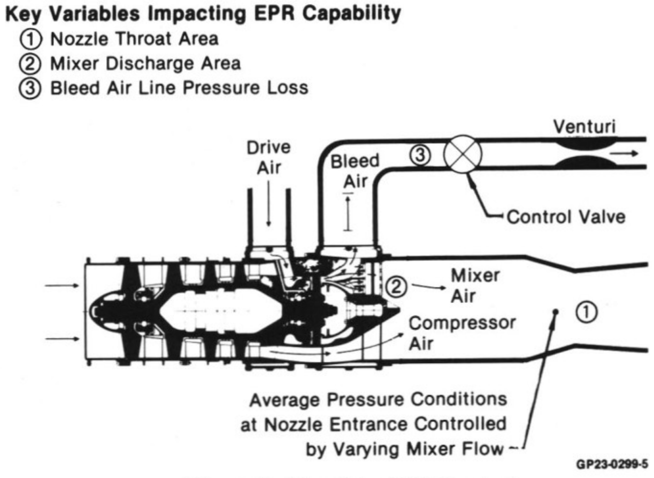


Figure 7. Simulator EPR Control

The range of EPR available with the simulator for a given model installation is dependent on three key variables; nozzle throat area (A_8), mixer discharge area (A_{e57}), and bleed air line pressure loss. Proper matching of the nozzle throat area and mixer discharge area represents the most critical element in attaining a wide range of EPR capability at a given compressor airflow. For example, the estimated mixer area effect on the simulator EPR/airflow performance flexibility is shown in Figure 8 for a fixed nozzle throat area (typical of engine dry power operation) and bleed air line pressure loss. With a solid mixer (zero mixer area), the flexibility is represented by a single operating line. As mixer area is increased, a flexibility envelope is produced. At small mixer areas, the maximum EPR line is limited by the mixer pressure limit (650 psia), while the minimum EPR line is limited by the amount of turbine discharge flow which can be routed overboard with the bleed air control valve fully open. As mixer area is increased, the maximum EPR line is raised until finally it is constrained by the 5% compressor stall margin line. Therefore, the "optimum" mixer area for a given nozzle throat area is defined as that area where the 5% compressor stall margin line and mixer pressure limit line coincide at the maximum EPR value. This mixer area provides the largest flexibility envelope for the specific nozzle area. When the mixer area is increased beyond this optimum value, more turbine discharge air will flow through the mixer because of the decreased mixer pressure drop. This will raise the minimum EPR line and thus reduce the overall flexibility.

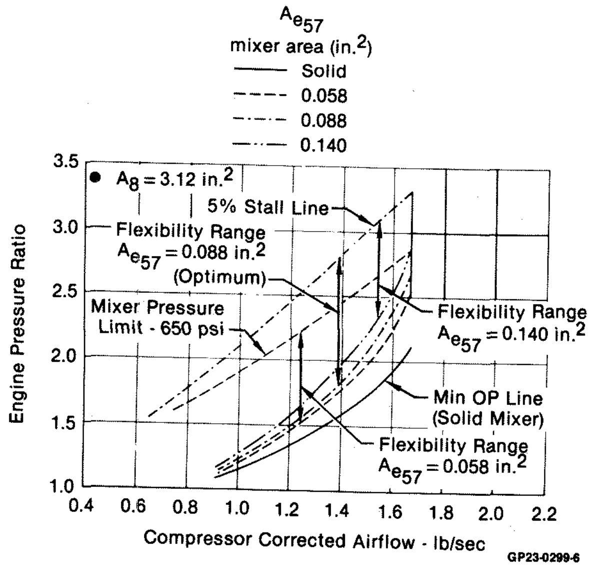


Figure 8. Estimated Mixer Area Effect on Simulator Performance Flexibility

As noted, the minimum EPR line for a specific nozzle throat area/mixer area combination is generally established by the amount of turbine discharge air that can be routed through the bleed air line with the control valve fully open. Any turbine discharge flow that cannot be routed through the bleed air line must be dumped through the mixer into the nozzle, which in effect raises the minimum EPR. As the bleed air line pressure loss is continually increased, the amount of flow that can be directed through the line continually decreases, forcing more air into the nozzle. Eventually, a condition is reached where it is no longer possible to power the simulator at maximum speed without stalling the compressor. Therefore, a low pressure loss turbine bleed air line system is important, especially for small throat area nozzles (typical of engine dry power operation) where the majority of the turbine discharge flow must be routed from the simulator through the bleed air line.

Early estimates of the simulator maximum flexibility that could be attained with various scaled nozzle throat areas is shown in Figure 9. These flexibility ranges, which assume a fixed bleed air system pressure loss, generally require more than one mixer area to attain the total range for a fixed throat area. The larger nozzle throat areas provide the largest performance flexibility. A larger area requires an increased amount of high pressure mixer air to fill the nozzle at a given simulator compressor speed, resulting in an increased nozzle pressure and engine pressure ratio. Similarly, if all turbine discharge air is routed out through the bleed air line, a low pressure ratio results for the larger area nozzles. Recent test data has indicated that a nominal 5% increase in EPR over the estimated levels shown in Figure 9 might be expected.

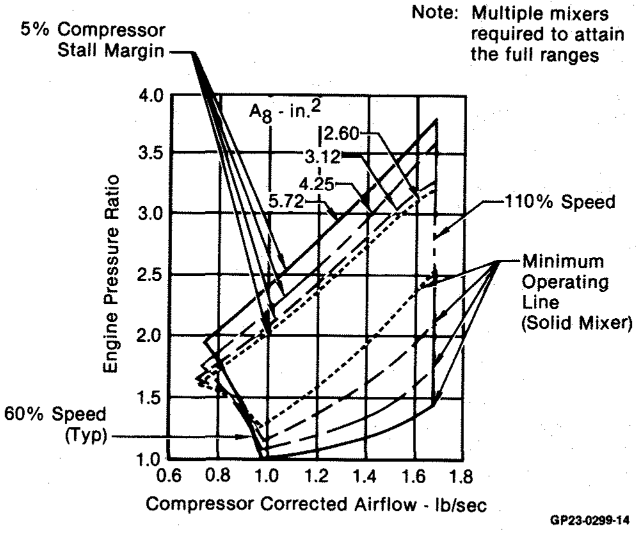


Figure 9. Simulator Performance Flexibility Estimates

Engine Cycle Simulation Capability

The engine cycle simulation capability of the supersonic propulsion simulator can be shown by comparing its performance flexibility against the operating lines (EPR versus airflow) of various current/near-term and typical advanced technology "paper" engines. Any lack of cycle simulation capability with the simulator would be most noticeable at the high engine power settings (i.e. maximum dry and maximum afterburning) where the engine pressure ratio is largest.

Representative trends of maximum EPR versus nozzle area are shown in Figure 10 for maximum dry and maximum afterburning power settings. These trends were established by examining various current/near-term and advanced technology engines, which included both turbojets and fixed/variable cycle turbofans with bypass ratios ranging from 0.2 to 2.0. The nozzle area for each engine was scaled using the model scaling relationship defined in the previous section. As anticipated, the trends show a reduction in maximum EPR and increase in nozzle area as engine bypass ratio is increased, for both the maximum dry and maximum afterburning power settings.

The current simulator estimated maximum EPR capability for a range of scaled nozzle areas is also identified in Figure 10. For the more moderate bypass ratio turbofans, the simulator possesses the capability to match the maximum EPR requirement. However, this capability falls somewhat short for low bypass ratio turbofans and turbojets. In a scaled model wind tunnel test, a moderate extrapolation of data to the higher EPR values would be required.

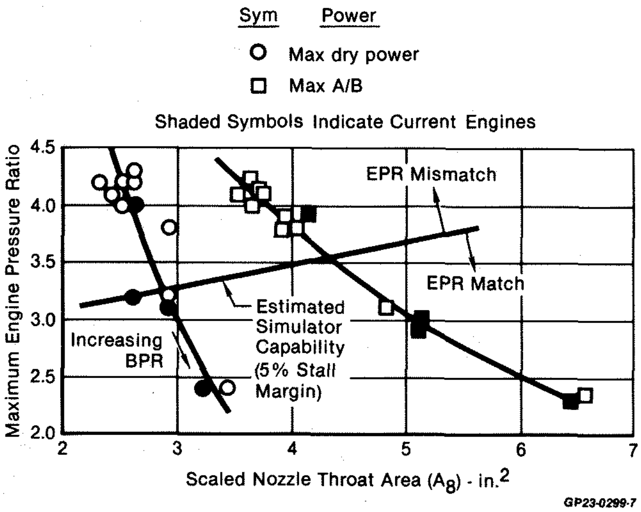


Figure 10. Typical Maximum EPR Variation for Advanced Engine Cycles

Even though the simulator maximum EPR may fall short of that required for advanced low bypass ratio turbofans or turbojets, the EPR mismatch generally decreases as the scaled airflow requirement is reduced, as illustrated in Figure 11. The reduced airflow requirement would be characteristic of throttling the engine back at subsonic, dry power conditions, or increasing supersonic Mach number operation at afterburning conditions.

In general, the current simulator design should provide the necessary engine cycle simulation capability for most advanced fighter wind tunnel model applications. In some cases, moderate data extrapolation to higher EPR levels may be required. If a future requirement for higher EPR levels becomes more abundantly clear, a next-generation simulator evolved from the current design might be desirable.

Wind Tunnel Model Installation Considerations

The decision to install supersonic propulsion simulators in a scaled wind tunnel model involves other considerations aside from the obvious one of investigating the potential for interactions between the inlet/airframe/nozzle flowfields. Two of the key considerations include (1) the ability to reasonably match the desired engine EPR characteristics, and (2) the ability to fit the simulator into a correctly scaled model. This last consideration is important since the physical size of the simulator could be larger than the scaled engine size. Therefore, on advanced fighter aircraft designs where there is a tight fuselage wrap around the engine, the simulator installation could require some distortion of the fuselage moldlines to accommodate the unit. A larger scale model could eliminate any moldline distortion compromises, but then the simulator airflow capability would not match that of the scaled engine.

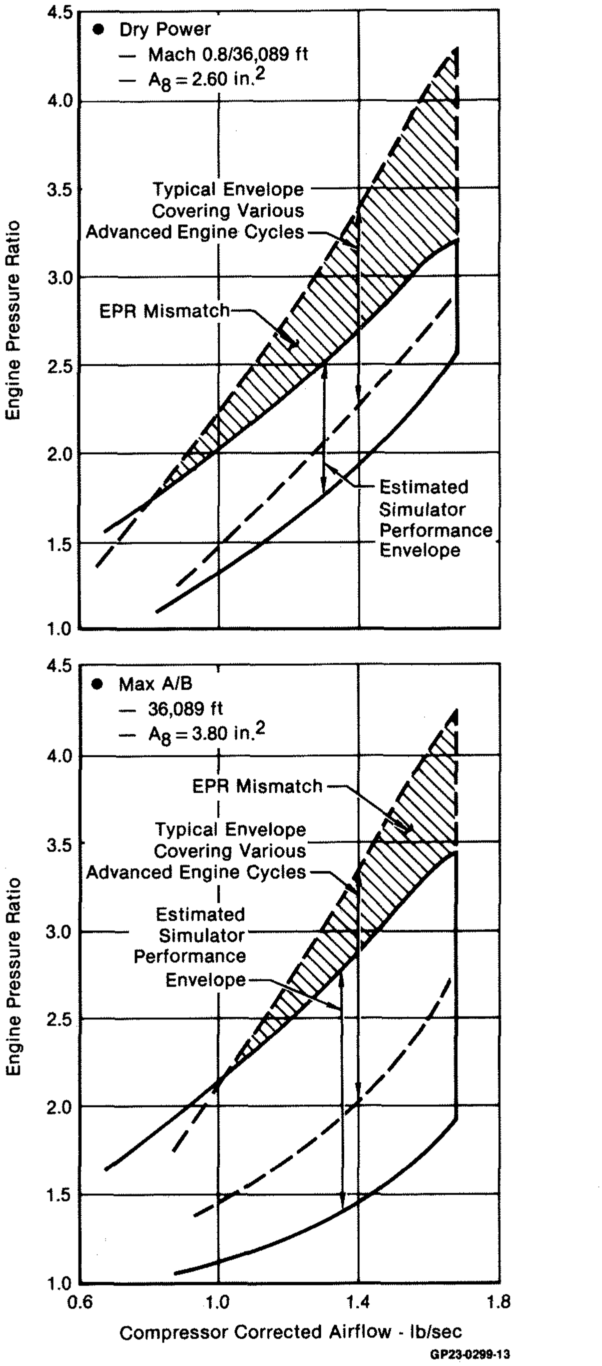


Figure 11. Comparison of Simulator Estimated Performance with Advanced Engine Cycles

Once the decision has been made to build a simulator-equipped model, there are some unique design problems that must be addressed. As encountered in previous wind tunnel model design efforts[5,7] utilizing these simulators, the primary problems that continually arise concerning the simulator installation are centered in three key areas: metric arrangement, mounting, and air line routing. These problems are generally a direct result of the relatively small 8% to 11% scale associated with these simulator-equipped models.

In every model design effort using simulators, a key decision to be made early is whether or not the simulator installation should be metric (i.e. thrust-minus-drag is measured on the force and moment balance). This decision is partially dependent on whether the internal performance of the nozzle(s) to be tested might be affected by the freestream flowfield. Past scale model testing of specific advanced nozzles, such as two-dimensional single ramp expansion or plug designs, have indicated such an effect at lower nozzle pressure ratios. In addition, for some aircraft configurations where there is a very tight engine wrap, there may be insufficient fuselage volume to isolate the simulator from the outer fuselage geometry without distorting the moldlines. A thrust-minus-drag balance arrangement may be the only alternative.

A non-metric simulator installation, as schematically illustrated in Figure 12, represents the easiest and most straightforward approach for scaled-model applications. With such an installation, the nozzle external boattail as well as the internal duct would be non-metric. The necessary boattail forces and moments would be determined through pressure-area integration of surface pressures. A flexible seal at the simulator compressor face would bridge between the metric inlet duct and non-metric simulator. A similar arrangement would bridge between the metric aft-fuselage and non-metric nozzle boattail.

For a metric simulator model design approach, the foremost installation problem involves the transfer of the four high pressure air lines (for a twin engine configuration) between metric and non-metric model hardware with minimum tare forces. Conventional nozzle air transfer systems using an opposed bellows arrangement do not appear suitable for these air lines, due primarily to the internal model volume requirements. In addition to the air lines, the bridging of the simulator instrumentation lines between the metric/non-metric hardware must be accomplished with minimal impact on the balance output.

One potential method of resolving these problems is to make the simulator "gas generator" non-metric, but maintain the nozzle duct metric, as illustrated in Figure 13. This technique would necessitate a single bellows or sliding labyrinth seal in the upstream nozzle duct to bridge between the metric/non-metric hardware.. The one possible drawback to this approach is the large momentum tare force correction at the seal station that must be made to the balance output. An accurate assessment of this tare force necessitates extremely accurate pressure and airflow force necessitates extremely accurate pressure and airflow measurements at that station. This approach still requires sufficient model volume to be able to isolate the simulator gas generator from the metric outer fuselage hardware.

It would appear that for metric simulator model applications, new approaches for installing the units whereby all tare forces are minimized must be developed. Special emphasis is required on methods of bridging the air lines between metric/non-metric hardware.

The mounting of the simulator inside scaled wind tunnel models will generally be independent of whether or not the simulator is metric to the force and moment balance. Two simulator mount locations at Engine Stations 0.264 and 6.320, Figure 14, are currently suggested for supporting the unit. With this arrangement, both bearings lie between the mounts (no bearing overhang), thus reducing any potential vibration impact on bearing integrity. Only one of the mounts should be used, however, to absorb or carry the simulator thrust loads. The other mount must be flexible in the axial direction to accommodate thermal growth of the simulator. The design of the mounts will, in most cases, be peculiar to the specific wind tunnel model installation. However, the standard mount designs used in recent simulator static tests, provide a starting point for consideration.

The turbine drive and bleed air lines into the simulator must also incorporate some provisions for slight axial movement to accommodate thermal growth of the unit. If the air lines are hard connect points, the thermal expansion of the unit could place undesirable stresses throughout the simulator. The possibility of using one of the air lines as the aft mount to support the unit and carry all simulator loads is not desirable, but may have application for some installations.

The layout of the required simulator drive and bleed air line system represents probably the most challenging design task associated with simulator-equipped models. In particular, the desire for a large bleed air line to minimize pressure loss is not compatible with a small support system, preferred for minimum aerodynamic flowfield interference. Based on previous simulator testing, a nominal bleed line area of 1.60 in^2 is considered desirable so that the simulator performance flexibility is not seriously degraded. However, such a large area over the entire length of the bleed air system is seldom practical. Based on the detailed design of a twin engine NASA V/STOL model with simulators[8], the actual bleed air line areas vary significantly from the simulator to the bleed air valve, as illustrated in Figure 15. In general, the areas inside the model are quite small, but enlarge once inside the support system. A detailed pressure loss analysis is considered essential during the model design process to ensure a minimum pressure loss in the bleed air line system. This analysis will aid in establishing the compromises needed to provide maximum simulator performance, as well as minimum support system size.

The standard drive and bleed air manifold designs for the simulator should be maintained whenever possible. However, as with simulator mounts, the standard port size/geometry on each manifold may not be practical with all realistic wind tunnel model installations. When test peculiar manifolds are necessary, the flow area distribution inside both manifolds should approximate that of the standard designs.

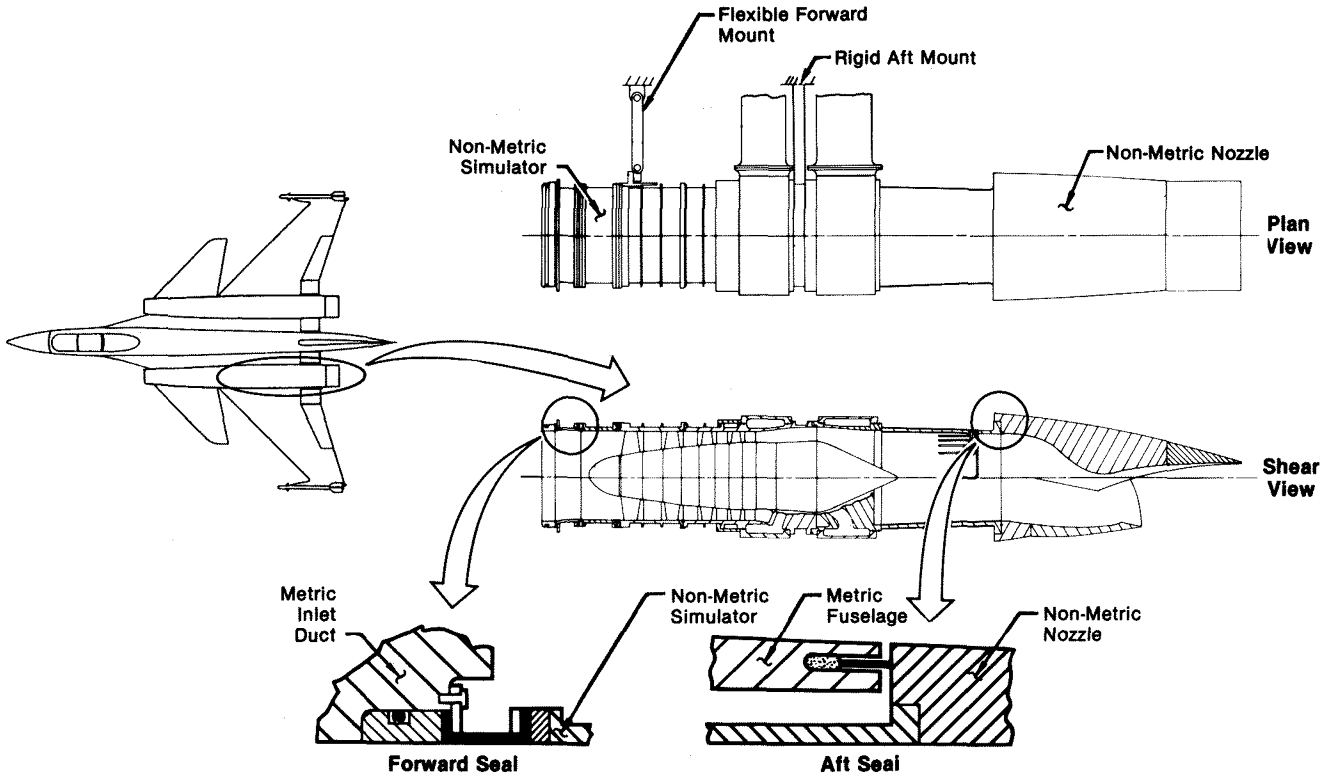


Figure 12. Typical Non-Metric Simulation Thrust Installation

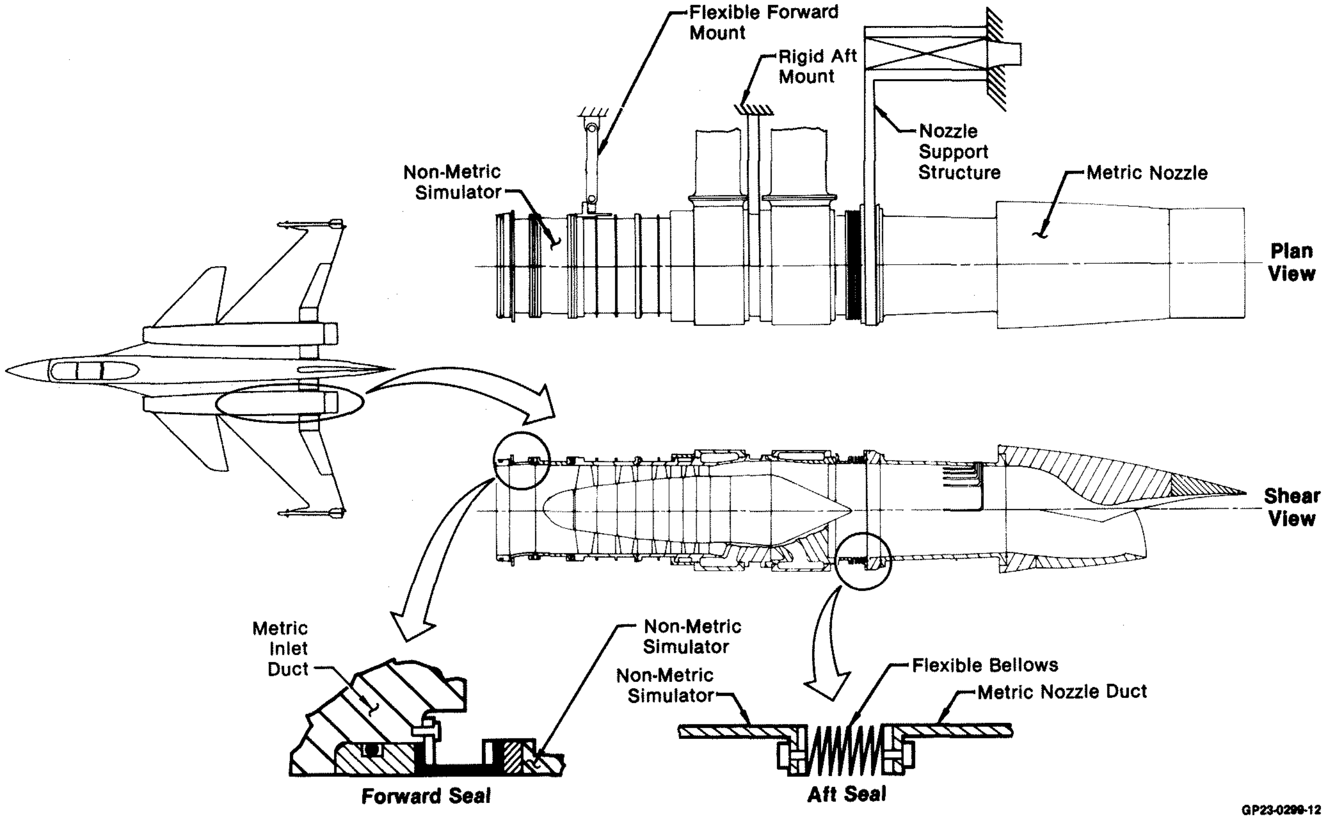


Figure 13. Potential Metric Simulator Thrust Installation

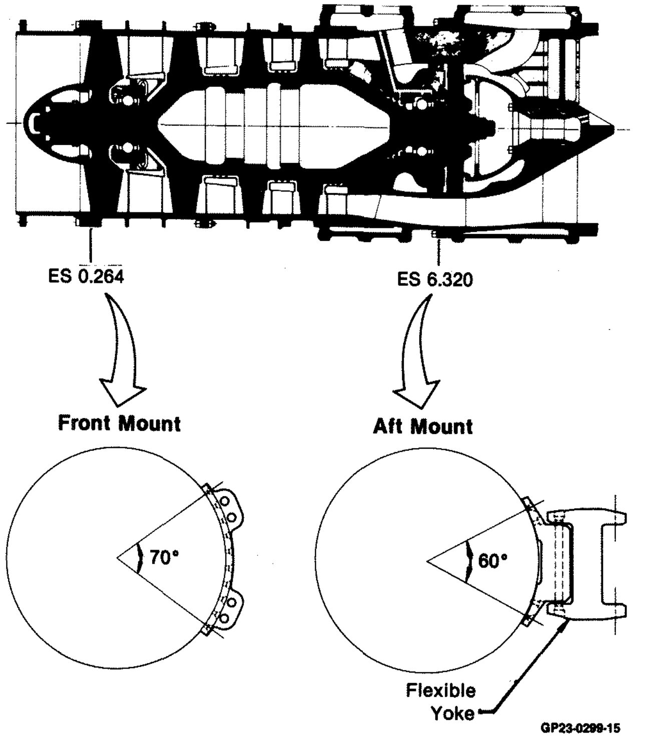
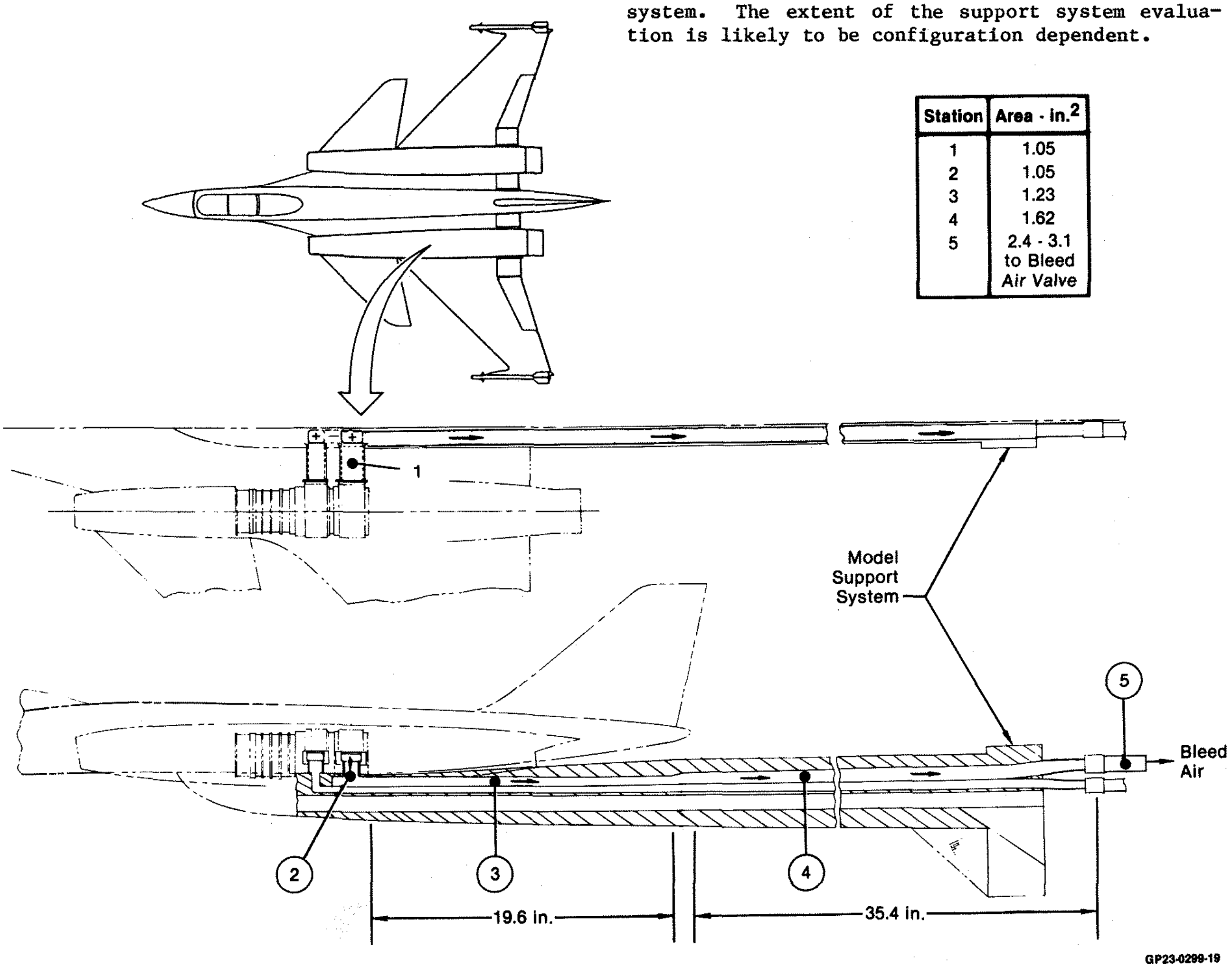


Figure 14. Typical Simulator Mount Designs

Thrust/Drag Accounting

The primary utilization of simulator-equipped wind tunnel models will be in the overall vehicle performance assessment. However, the exact role that these models would play in that assessment could vary, depending on the manner in which the thrust and drag performance elements are selected to be built up. The thrust/drag accounting system(s) selected should attempt to maximize the use of the simulator's unique capabilities to provide for the simultaneous simulation of the complete propulsion system geometries and flowfields. Two possible thrust/drag accounting systems developed specifically around these capabilities are schematically shown in Figures 16 and 17.

In the thrust/drag accounting system shown in Figure 16, a strut-supported simulator-equipped model is used to obtain the aircraft aerodynamic performance directly at the correct inlet/nozzle geometry and flow conditions (dependent on engine cycle characteristics). The only corrections to this aerodynamic data would be due to the strut support system. It is not clear at this time, however, whether the evaluation of these support system interference increments would necessitate the simulation of the propulsion system flowfield. If such simulation is required, then the basic simulator-equipped model would require the capability to be tested with an alternate support system. The extent of the support system evaluation is likely to be configuration dependent.



Station	Area - in.^{2}
1	1.05
2	1.05
3	1.23
4	1.62
5	2.4 - 3.1 to Bleed Air Valve

Figure 15. Typical Simulator Bleed Air Line Area Variation

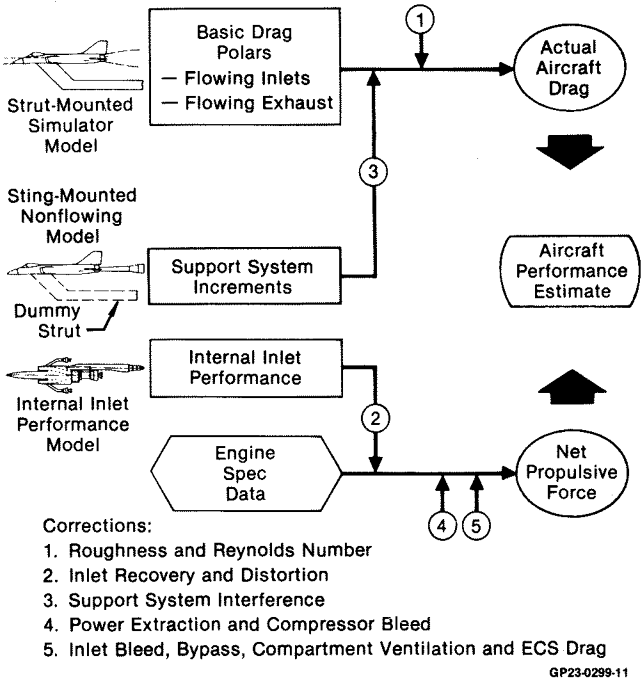


Figure 16. Thrust/Drag Accounting System Using Simulator Model for Basic Aerodynamic Performance

In the assessment of net propulsive force, no inlet drag or jet effects drag increments are required, since the basic aerodynamic performance is obtained at the correct inlet/nozzle flow conditions. Internal inlet performance as obtained from a large scale wind tunnel model would still be necessary however.

This accounting system provides for the most direct evaluation of the overall aircraft performance using a minimum number of wind tunnel models. The accuracy of the performance estimates might therefore be expected to be improved over other systems, with the only significant uncertainty being the capability to correct the aerodynamic data for model support interference. However, one major disadvantage is that this system would allow virtually no visibility into the throttle-dependent effects (i.e., inlet drag and jet effects drag variation). It would therefore be difficult to isolate the exact cause of any aircraft performance problem, which could be due to either the basic aerodynamic design, propulsion system integration, or basic engine performance.

In the thrust/drag accounting system shown in Figure 17, maximum visibility into the throttle-dependent effects is available. With this system, the basic aerodynamic performance is obtained from a simple aerodynamic model with non-flowing inlets and nozzles. These non-flowing reference conditions are represented by faired inlets and maximum open nozzles with solid exhaust plumes. Such reference conditions would ensure that all throttle-dependent performance effects (including flowfield interactions) are determined on a simulator-equipped model. Depending on the configuration, the solid plumes could be made to serve as a minimum interference sting support system for this model, thus requiring no other support system interference testing.

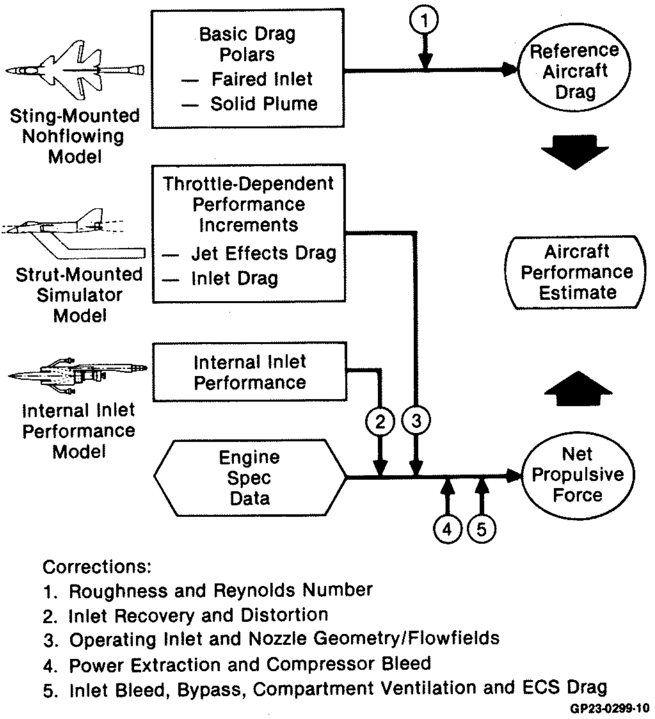


Figure 17. Thrust/Drag Accounting System Using Simulator Model for Throttle-Dependent Effects

A strut-supported simulator-equipped model is used to determine the throttle-dependent performance increments, including the effects of both the inlet and nozzle geometries and flow conditions, as well as all related flowfield interactions. As set up, it is assumed that the simulator model support system effects are independent of the inlet and nozzle flow conditions. Thus, the throttle-dependent performance increments would be valid. These throttle-dependent increments are combined with the internal inlet performance data and engine data for an assessment of the net propulsive force characteristics.

The above accounting systems are only two possible candidates for use with simulator-equipped models. Variations of each of these systems can certainly be defined. But ultimately, the best system(s) for building up aircraft performance using simulator-equipped models will evolve only as considerable experience in the utilization of such models is obtained. However, with the complete propulsion system flowfield simulation capability afforded by the simulator, it is not unreasonable to believe that current thrust/drag accounting philosophy will undergo changes.

Usage in Aircraft Development Cycle

For the supersonic propulsion simulator to be an effective test tool, it is necessary to know when, as well as how, to use it. The obvious use is the evaluation of vehicle performance, once the configuration has been defined. But it would appear that this capability could also be used earlier, while the aircraft design is evolving. This would allow the design to be optimized considering any inlet/airframe/nozzle flowfield interaction effects.

Under a previous Air Force-sponsored study,[10] parallel and integrated plans for the systematic development of future fighter airframe/engine systems were defined. An example of one of the plans is presented in Figure 18. Three levels of airframe and engine technology data form the basis for this plan.

- Level I - General theoretical and empirical data which are sufficiently applicable to the engine and airframe designs under consideration to ensure a viable concept.
- Level II - Specific airframe and engine test data representative of the general system elements sufficient to conduct optimization trade studies and establish the airframe and engine performance levels.
- Level III - Specific airframe and engine test data on the final refined system sufficient to ensure the required performance levels.

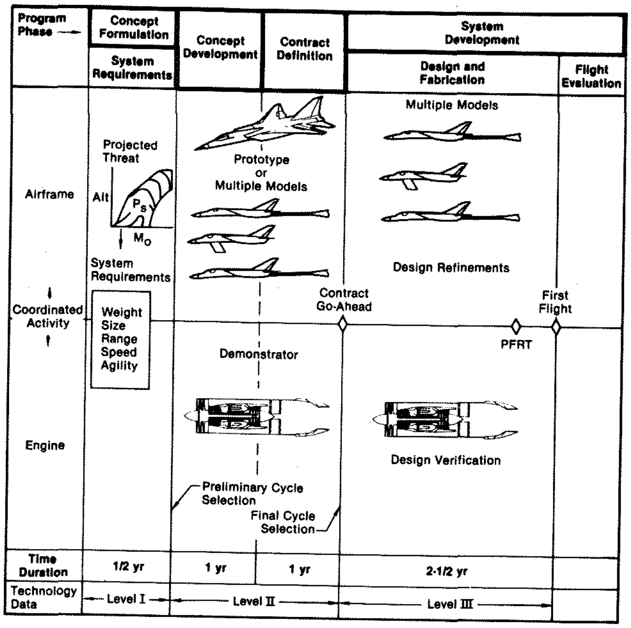


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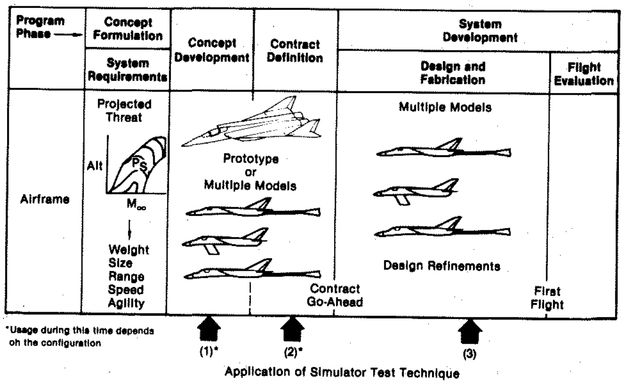
Figure 18. Example Engine/Airframe Development Plan

In the Concept Formulation phase where Level I technology data is used, the detailed airframe/propulsion system integration has not yet evolved. Hence, use of the simulator during this time would probably be premature. However, during the Concept Development and Contract Definition phases, the engine cycle is defined, airframe arrangement selected, and most important, details of the inlet/engine/nozzle integration with the fuselage are evolved. It is during these two phases that the simulator can offer the most benefit as a testing tool.

Three placements within the overall airframe development cycle in which use of simulator-equipped model testing would be most effective are identified in Figure 19. The first placement indicated is in the Concept Development phase. Ideally, this would be one of the first tests conducted after the basic configuration has been defined and initial engine cycle selected. Use of the simulator at this time allows three important assessments to be made:

- A realistic evaluation of the propulsion system installation losses.
- A determination of how important airframe/engine integration is in the optimization procedure for that particular system.
- An evaluation of inlet/airframe/nozzle flowfield interactions to determine if these effects have to be simulated in future optimization testing.



GP23-0299-2

Figure 19. Supersonic Propulsion Simulator Usage in Airframe Development Cycle

The amount of additional testing conducted with a simulator-equipped model in this phase would depend on the results of the three previous assessments. If installation losses are large and configuration dependent, requiring complete simulation of the propulsion system flowfields, then perhaps further development work would be conducted on a simulator-equipped model. If the above characteristics are not indicated by this first testing, then further development and optimization testing could be performed using more conventional wind tunnel model concepts.

The second possible placement shown is in the Contract Definition phase. The airframe configuration may have changed significantly from that tested in the first simulator tests as a result of optimization and configuration trade-off studies. The results of simulator model testing at this time would be used as the basis for assessing the impact of these changes on the overall vehicle performance characteristics.

After contract go-ahead, detailed airframe design is accomplished in the System Development phase. During this time period, additional testing is usually conducted to refine specific areas of the design. This represents the third possible application of simulator-equipped models.

Each of the three placements suggested for simulator model testing achieves a separate objective in the overall airframe development cycle. The first use is effective in achieving overall system optimization by early assessment of the potential installation losses. Information is also obtained to determine if simulator-equipped models should be used throughout the development testing to enable simulation of inlet/airframe/nozzle flowfield interactions. The second placement is effective in providing a realistic evaluation of the aerodynamic performance characteristics of the final configuration. The third placement serves to ensure that changes incorporated during the detailed design, either to the airframe or the engine cycle, have not degraded the expected performance.

Conclusions

The development of the supersonic propulsion simulator was undertaken to provide simultaneous simulation of inlet/airframe/nozzle flowfields on a single wind tunnel model. Major observations concerning the future use of simulator-equipped models for tactical fighter development are as follows:

- The most effective use of simulator-equipped models will be on those configurations where there is a strong potential for inlet/airframe/nozzle flowfield interactions. Such configurations will probably feature more highly-integrated and closely-coupled propulsion systems than on current fighter designs.
- The current simulator capability to vary compressor airflow and EPR will allow the simulation of advanced moderate bypass ratio turbofan cycles. The simulation of low bypass ratio turbofan or turbojet cycles may be somewhat limited in terms of maximum EPR capability.
- Scaling of wind tunnel models by matching the maximum simulator airflow with the maximum required engine airflow will generally result in an 8% to 11% scale model.
- In scaled wind tunnel model applications, a non-metric simulator installation is the most straightforward approach. For metric simulator model applications, new approaches for bridging high pressure air lines between metric/non-metric hardware with minimum tare forces appear to be required.
- The use of simulator-equipped models offers new possibilities for thrust/drag accounting which were not previously available due to the lack of simultaneous inlet/airframe/nozzle flowfield simulation.
- The most effective placement of simulator model testing in an aircraft development cycle will probably occur following selection of the engine cycle, airframe arrangement, and general propulsion system integration. Usage prior to this time during general parametric studies would be premature.

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