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A STATUS REPORT ON HIGH ALPHA TECHNOLOGY PROGRAM (HATP) GROUND TEST TO FLIGHT COMPARISONS

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A Status Report on High Alpha Technology Program (HATP)
Ground Test to Flight Comparisons

In this paper two topics are reviewed. The first is a testing technique, high-α gritting, that promises to significantly improve the correlations between ground test and flight data. The second portion addresses the status of the High Alpha Technology Program (HATP) Experimental Aerodynamics Working Group. One of the key objectives of the Working Group is to make sure that critical comparisons are made of ground test to flight data. The co-authorship of this report reflects the members of both the Working Group and a key researcher from Ames Research Center who is actively involved in the ground test to flight correlations.

A STATUS REPORT ON HIGH ALPHA TECHNOLOGY PROGRAM (HATP) GROUND TEST TO FLIGHT COMPARISONS

- Introduction
- Importance of Reynolds number in simulating forebody pressures
- Improvement of correlations with high-α gritting techniques
- Final tests planned
- Comments on HATP Experimental Aerodynamics Working Group

Abstract

This status paper reviews the experimental ground test program of the High Alpha Techology Program (HATP). The reasons for conducting this ground test program had their origins during the 1970's when several difficulties were experienced during the development programs of both the F-18 and F-16. A careful assessment of ground test to flight correlations appeared to be important for reestablishing a high degree of confidence in our ground test methodology. The current paper will then focus on one aspect of the HATP program that is intended to improve the correlation between ground test and flight, high-α gritting. The importance of this work arises from the sensitivity of configurations with smooth-sided forebodies to Reynolds number. After giving examples of the effects of Reynolds number, the paper will highlight efforts at forebody gritting. Finally, the paper will conclude by summarizing the charter of the HATP Experimental Aerodynamics Working Group and future experimental testing plans.

INTRODUCTION - MOTIVATION FOR HATP TESTING PROGRAM

- Experience since the 1970's on vortex dominated configurations demonstrated need for improving high-α prediction capability of ground test methodology
  - F-16, pitchup and deep stall
  - F-18, lateral / directional departure susceptibility

- Vast majority of high-α aerodynamics configuration development conducted in sub-scale low / moderate Reynolds number wind tunnels

Introduction–Motivation for HATP testing program

During the 1970's, testing programs with both the F-16 and F-18 experienced difficulties, see reference 1. For the F-16, a deep stall was discovered during the flight test program which was not anticipated on the basis of ground test data. This necessitated an enlargement of the horizontal tail. Similarly, the F-18 experienced lateral/directional shortcomings in its flight test program that required a rescheduling of the wing leading-edge flaps. At least one aspect of the incorrect predictions has involved the subscale Reynolds number effects during the model tests.

INTRODUCTION - OBJECTIVES OF HATP EXPERIMENTAL PROGRAM

- Address fundamental understanding of vortical flows about F/A-18 as an example high-α vehicle
  - Reynolds number and Mach number effects
  - Vortex flow physics
  - Lack of prediction of departures
- Provide key correlations between tunnel / flight / CFD
- Support test technique development

Introduction–Objectives of HATP experimental program

The objectives of the HATP program included (1) detailing Reynolds and Mach number effects, (2) increasing our fundamental understanding of the vortical flows about the F-18, as an example vehicle, and (3) determining if there was a systematic problem that led to the unexpected departures with the F-18. Correlations between tunnel, CFD, and flight are also considered to be an important priority. A final goal was to utilize HATP to foster test technique development.

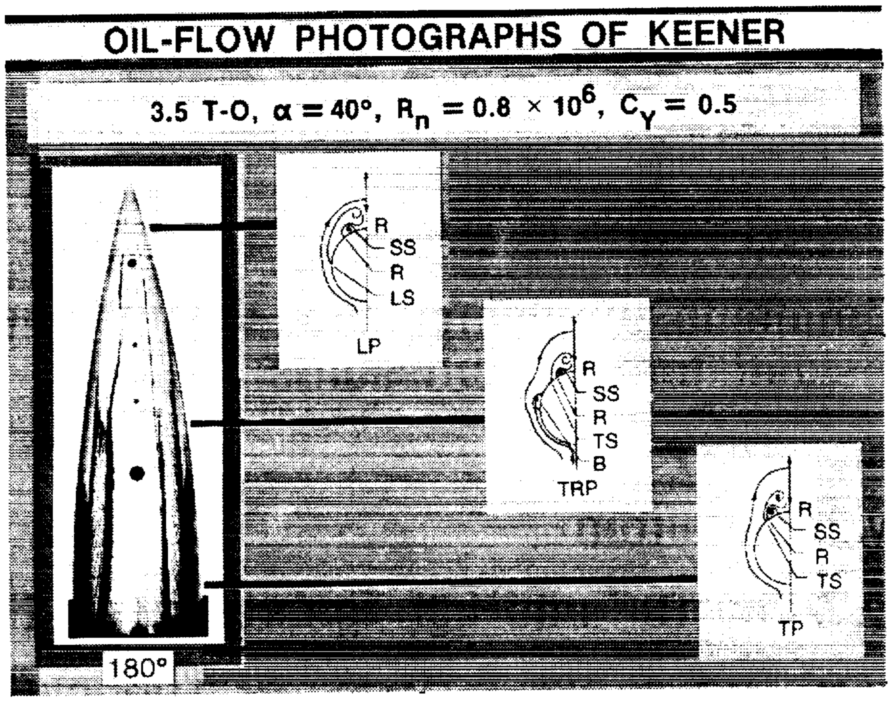
IMPORTANCE OF REYNOLDS NUMBER IN SIMULATING FOREBODY PRESSURES

- General comments about impact of Reynolds number on smooth-sided forebody pressures

- Illustrate with data from
  - Langley 7- by 10-Foot High Speed Tunnel (HST)
  - Langley Low-Turbulence Pressure Tunnel (LTPT)

Importance of Reynolds number in simulating forebody pressures

The impact of Reynolds numbers on smooth-sided forebodies has been an active subject in the literature, see references 2 to 10. It has often been a source of differences when comparing model-to-model, tunnel-to-tunnel, and tunnel-to-flight data. The magnitude of these effects will be highlighted with data from two Langley experiments–a conventional, moderate Reynolds number test in the Langley 7- by 10-Foot High Speed Tunnel (HST) and a high Reynolds number test in the Langley Low-Turbulence Pressure Tunnel (LTPT).



Oil Flows illustrating Reynolds number effects

Earlier research by Keener, see reference 10, contributed to our understanding of Reynolds number effects by interpreting a series of oil flows and sketching the corresponding flow topologies. The three topologies documented by Keener are shown and occur when (1) the boundary layer separates in a laminar fashion, see the sketch LP, (2) the boundary layer separates in a laminar fashion but reattaches before separating a second time as a turbulent boundary layer, see sketch TRP, and (3) the boundary layer transitions to turbulence before it has a chance to separate in a laminar manner, see sketch TP. Each of these topologies has a characteristic pressure signature and results in different separation locations and strengths of vortical suction on the surface.

1992 EXPERIMENT IN LANGLEY 7- by 10-FOOT HIGH SPEED TUNNEL (HST)

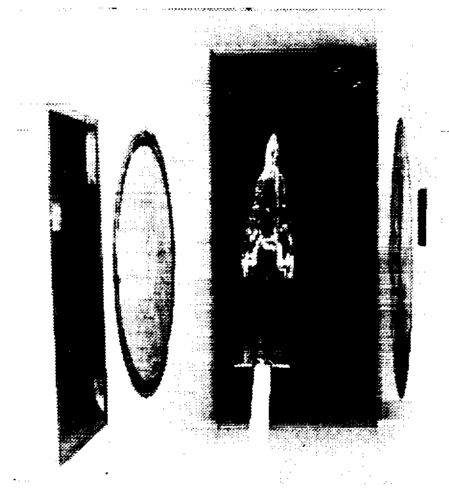
- Tested pressure instrumented 6% forebody on NAVAIR / McDonnell Douglas 6% high speed model
- Force and moment as well as pressure data recorded
- Conditions:
  - $M_\infty = 0.08$ and 0.30
  - $p_t = 1$ atm
  - $R_C = 0.4$ and 1.4 million
  - $-2° < \alpha < 40°$
  - $-10° < \beta < 10°$
- Tested 4 different gritting patterns, leading edge flap settings of 25° and 34°, flight test nose boom on and off

1992 Experiment in the Langley 7- by 10-Foot High Speed Tunnel (HST)

A cooperative experiment with NAVAIR and McDonnell Douglas was designed to gather pressure data with a Langley-manufactured forward fuselage (black component in photograph) mounted on the aft fuselage and wings of the 6% high speed model. The Langley forebody is equipped with a subset of the flight pressures, although not all of the orifices were active during this test. Data were taken at values of Mach number, M_∞, equal to 0.08 and 0.3 while angle of attack, α, varied from -2° to 40° and angle of sideslip, β, from -10° to 10°. Major objectives of this test included exploring high-α gritting patterns and examining the impact of flight test nose boom on configuration stability and control. Results of this test are also discussed in reference 11.

1994 EXPERIMENT IN LANGLEY LOW-TURBULENCE PRESSURE TUNNEL (LTPT)

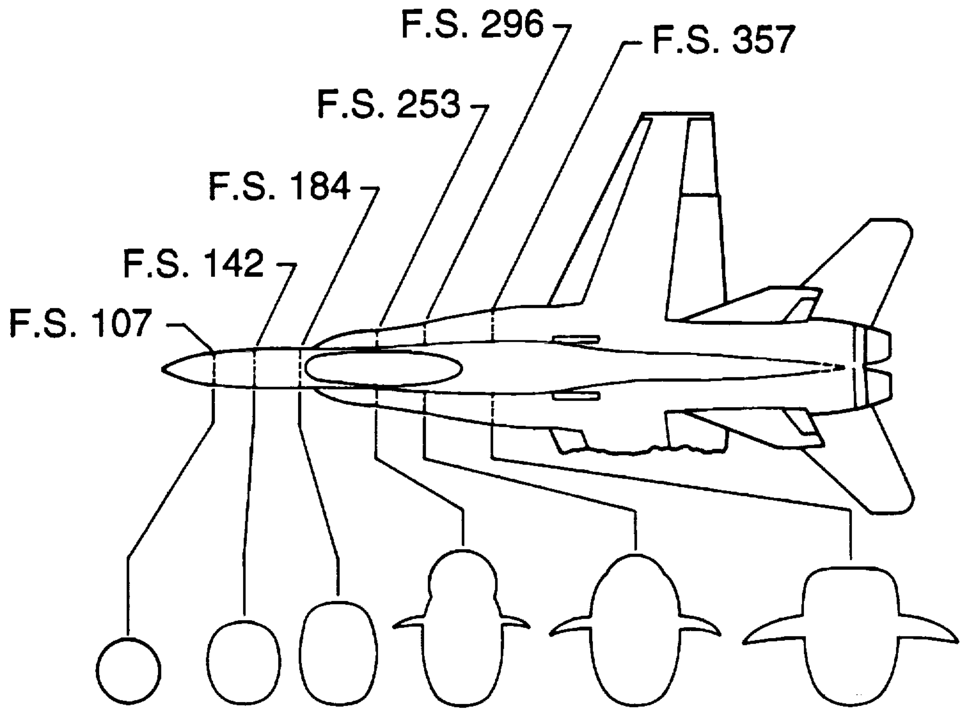
- Tested pressure instrumented 6% forebody and LEX on afterbody with constant cross section
- Only pressure data recorded
- Conditions:
  - $0.1 < M_\infty < 0.3$
  - $1 < p_t < 10$ atms
  - 0.48 million $< R_c <$ 6.9 million
  - $-10° < \alpha < 50°$
- Tested 5 different gritting patterns



1994 Experiment in the Langley Low-Turbulence Pressure Tunnel (LTPT)

The same Langley pressure-instrumented forebody was also outfitted with a constant cross section afterbody attachment, called a shroud. The constant cross section shroud afterbody begins where the leading edge flaps would intersect the fuselage. The length of the forebody/shroud configuration is 37.52 inches. While this forebody/shroud configuration was originally used for CFD code validation, see reference 12, it has also proved to be a useful tool for forebody studies. All values of Reynolds numbers, R_c, are calculated using the full configuration mean aerodynamic chord length. As will discussed, gritting patterns designed for high-α flows were also tested. LTPT, which is a pressure tunnel capable of operating at $M_\infty = 0.2$ up to 10 atmospheres of pressure, is ideal to explore Reynolds number variations. The tunnel is 3 feet wide and 7.5 feet high, which makes it ideal for a slender body test such as this.

FOREBODY AND LEX SURFACE STATIC PRESSURE MEASUREMENT STATIONS

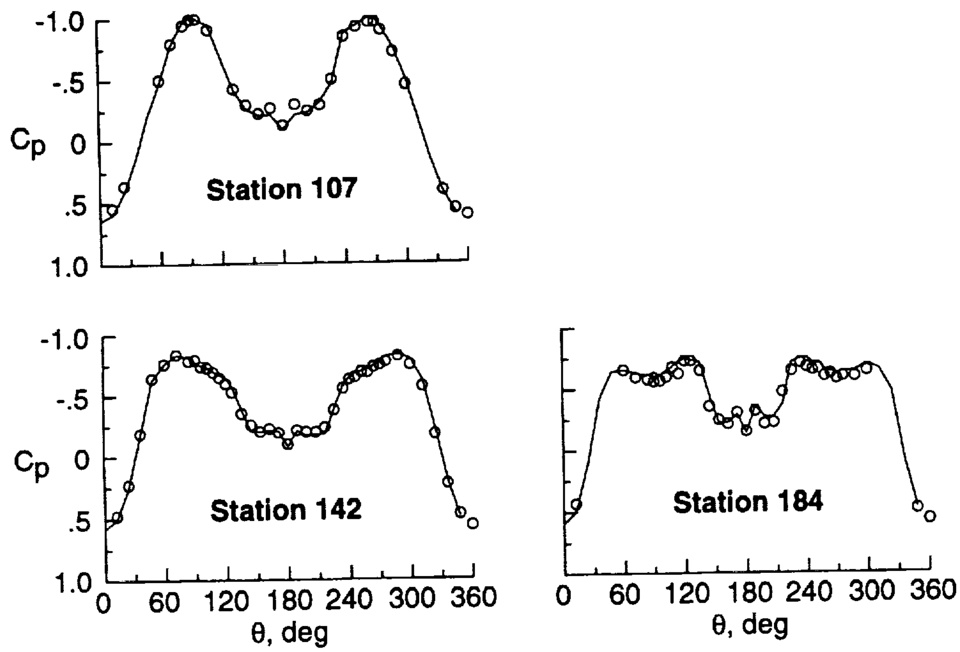


Forebody and LEX surface static pressure measurement stations

The location of the pressure rows on the forebody and the LEX are shown here for the entire configuration and are, of course, the same for the forebody/shroud configuration.

VALIDATION OF FOREBODY / SHROUD MODEL

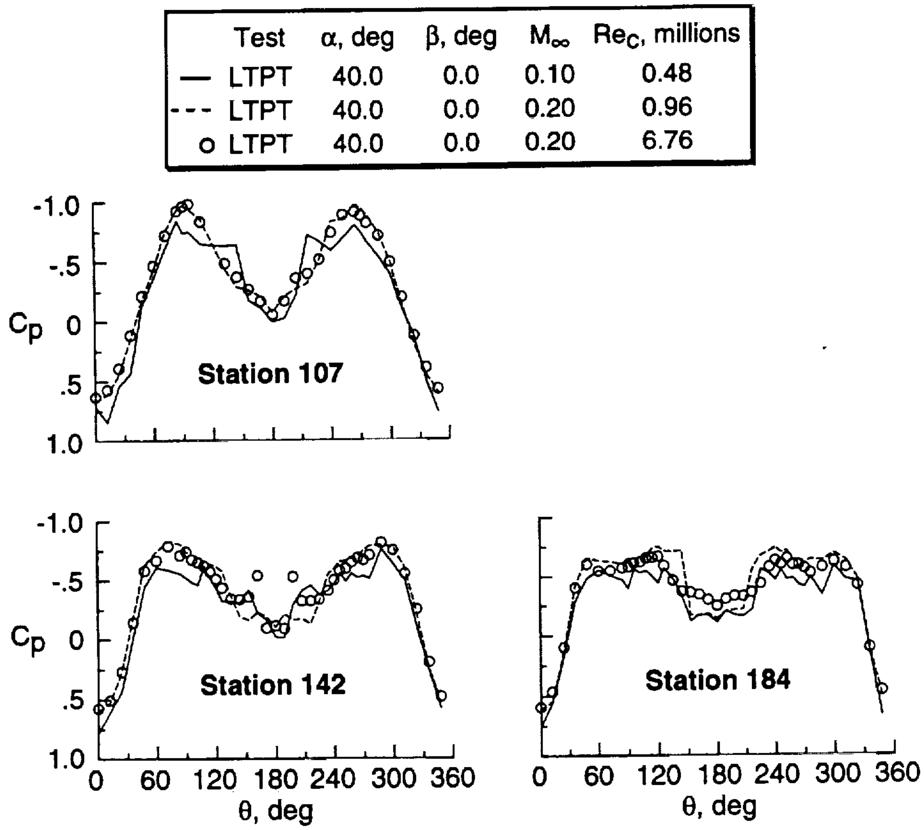
	Test	α, deg	β, deg	M_∞	Re_c, millions
—	LTPT	40.0	0.0	0.30	1.41
o	7 x 10	40.3	0.0	0.30	1.36



Validation of the forebody pressures from the forebody/shroud model

The pressures from forebody Stations 107, 142, and 184 of the forebody/shroud model are compared to the forebody pressures from the complete configuration tested in the Langley 7- by 10-Foot HST. The plots show pressure coefficient as a function of azimuthal location, θ, around the forebody. Values of θ equal to 0° and 360° are on the windward plane of symmetry while 180° represents the leeward plane. Values of θ increase in a clockwise direction as viewed from the pilot's perspective. The forebody pressures are not influenced by the presence or absence of the wing and empennage of the full configuration, as evidenced by the good agreement in the figure. (While not shown here, the LEX pressures are different between the forebody/shroud model and the complete configuration.) The large minimum pressure peaks at Fuselage Station 107 result from the attached flow accelerating about the body maximum breadth at 90° and 270°. The attached flow maximum velocities occur at Fuselage Station 142 at approximately 72° and 288°. At Fuselage Station 142, the distribution in the region between 144° and 216°, while relatively flat in these comparisons, will be the area that will be most sensitive to Reynolds number.

REYNOLDS NUMBER EFFECTS IN LTPT

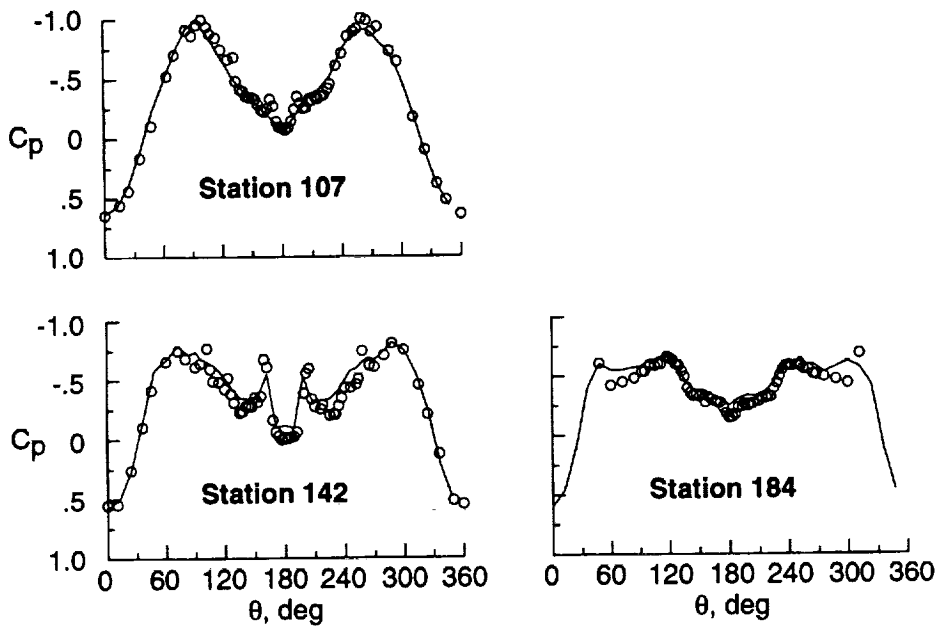


Reynolds number effects in LTPT

This figure summarizes three data points taken over a wide range of Reynolds number. As discussed by Polhamus in reference 8, Mach number effects on the forebody are insignificant as long as the cross-flow component of M_∞ is less than 0.15. For $\alpha = 40°$, consequently, any differences between data for $M_\infty = 0.1$ and for $M_\infty = 0.2$ would only be the result of Reynolds number differences. However, the values of pressure coefficient for the lowest Reynolds number data are subject to the largest error bars. Assuming a nominal accuracy of the electronically scanned pressure transducer of 0.2 percent of full scale, the respective uncertainty in C_p for the different test points comes out to be $\pm.2$ for the 0.48 million data, $\pm.05$ for the 0.96 million data, and $\pm.007$ for the 6.76 million data. This difference in error bars helps to explain why the lowest Reynolds number data appear rough compared to the other data. Turning our attention to the Station 142 distribution, it is seen that at the low Reynolds numbers, there are vortex footprints at azimuthal locations of 153° and 216°. These footprints go away for intermediate values of Reynolds number, such as for the 0.96 million example and as seen in the previous figure for the comparison with the 7- by 10-Foot HST data. At much higher values of Reynolds number, these footprints come back, as seen for 6.76 million. Unfortunately, much of wind tunnel testing at high-α falls in the intermediate Reynolds number range where the vortex footprints do not resemble the high Reynolds number limits. While the lower Reynolds number data do show the vortex footprints, please note that other significant differences in the pressure distributions are quite obvious at all three fuselage stations.

CORRELATION OF LTPT DATA WITH FLIGHT

	Test	α, deg	β, deg	M_∞	Re_C, millions
—	LTPT	40.0	0.0	0.20	6.76
o	Flight	39.7	-0.3	0.25	9.57



Correlations of the LTPT high Reynolds number data with flight

Since the pressures over the forebody/shroud model represent the forebody pressures of the entire configuration, it is now possible to determine if the high Reynolds number data out of the LTPT entry match the flight data from the HARV. The values of R_c are of the same magnitude, with a value of 6.76 million for the LTPT test and a value of 9.57 million for the flight data. The agreement is reasonable, in general, and good in the vortex footprint region at Station 142 for $144° < \theta < 216°$. As will be described in more detail by Fisher and Lanser, see reference 13, some of the spikes in the flight data are due to external protuberances on HARV.

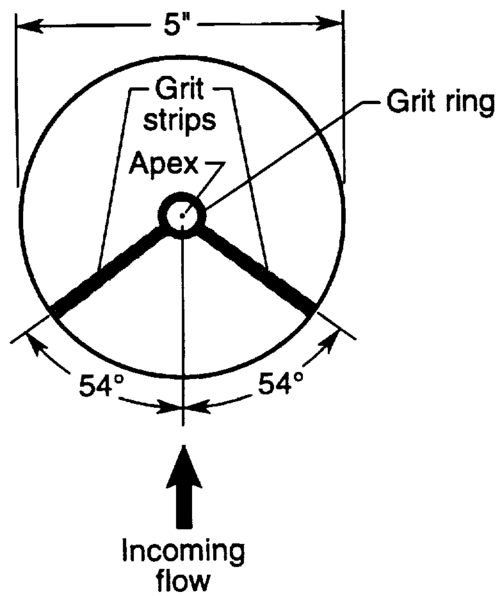
IMPROVED CORRELATIONS WITH GRITTING

- Approach
- 7- by 10-Foot High Speed Tunnel entry
- LTPT entry

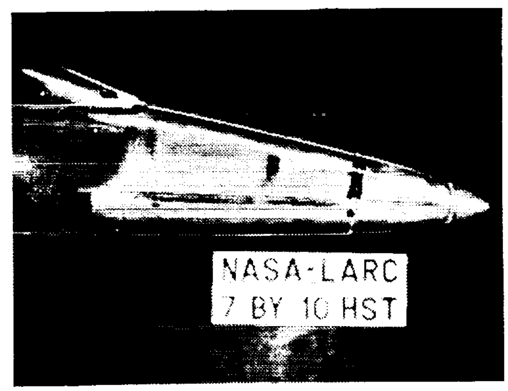
Improved correlations with gritting

Although correlations of high Reynolds number data from LTPT with flight data are good, low speed data are often limited to significantly lower Reynolds numbers. Therefore, test techniques to simulate the high Reynolds number flow, such as high-α gritting, are important to develop. While gritting for low-α has been successfully employed for many years, see reference 14, no similar systematic approach has been documented in the literature for high-α gritting. For the high-α application, the grit must be able to trigger boundary layer transition at model attitudes where the streamlines are predominantly in the cross-flow direction, and not in the longitudinal direction. Background information will be presented on gritting strategy and data from two Langley experiments will be given.

SCHEMATIC OF GRITTING APPROACH



(a) For generic ogive / cylinder model

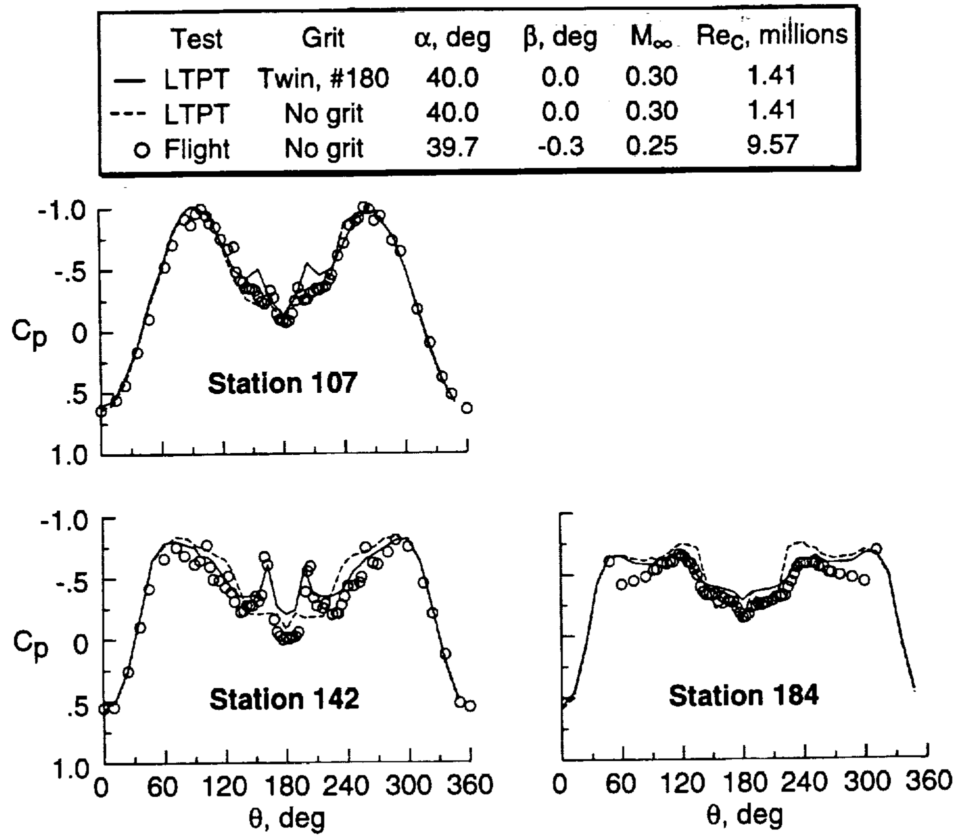


(b) For 6% F-18 model

Schematic of gritting approach

The most successful approach found during the Langley development of high-α gritting is the twin strip pattern. The idea is to place strips of grit longitudinally along the body so that the flow, when traversing the body in the cross-flow direction will pass over the grit and transition not only before separating but also before reaching its maximum attached flow velocity, see reference 15. For a generic ogive/cylinder, an azimuthal angle that works well is about 54°. For the F-18 configuration, azimuthal angles on the order of 54° or 72° seem to work well. An example of a twin strip pattern on the 6% F-18 forebody is also shown. While the traditional grit ring is ineffective at high-α, it is retained to trip the flow at lower values of α as seen both in the schematic and in the photograph of the F-18 forebody.

CORRELATION OF LTPT GRITTING DATA WITH FLIGHT

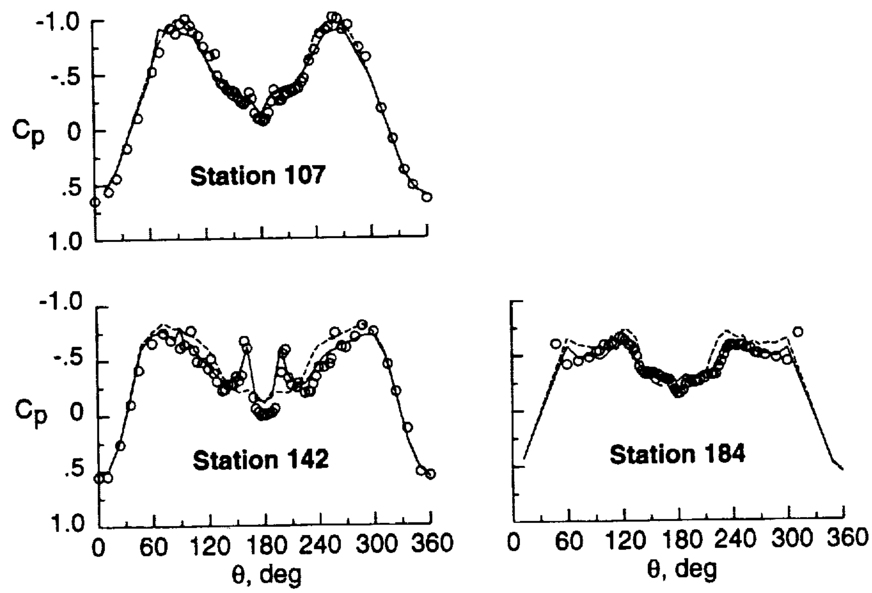


Correlation of the LTPT gritting data with flight data

The worth of the gritting pattern is whether it improves the correlation with high Reynolds number, flight data. This figure compares LTPT data for 1 atmospheres and $M_\infty = 0.3$ for both gritted and ungritted cases compared to flight. With the exception of overpredicting vortex strength at Station 107 (the suction peaks at azimuthal locations of 156° and 204°), the gritting greatly improved correlations at Station 142 in terms of matching vortex suction peaks as well as more closely matching pressure gradients on the leeward side of the maximum attached flow suction peaks. Agreement is also enhanced at Station 184. The grit size used was #180.

CORRELATION OF 7-by 10-FOOT HST GRITTING DATA WITH FLIGHT

Test	Grit	α, deg	β, deg	M_∞	Re_C, millions
— 7 x 10	Twin, #180	39.4	0.1	0.30	1.39
--- 7 x 10	Nose ring only	40.3	0.0	0.30	1.36
o Flight	No grit	39.7	-0.3	0.25	9.57

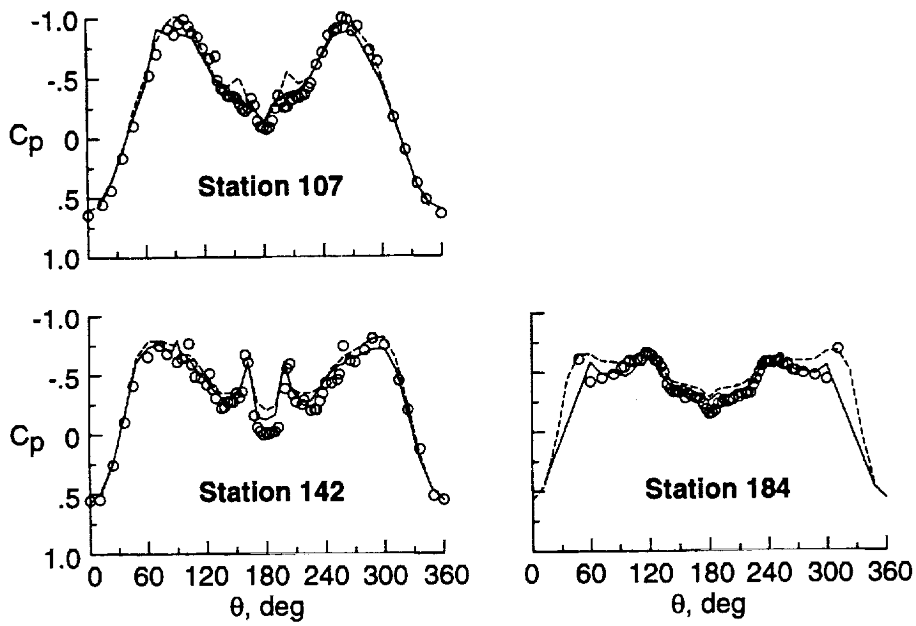


Correlation of the 7- by 10-Foot HST gritting data with flight data

This agreement between the gritted data and flight is also good. This application of grit did not produce excessive vortex footprints at Station 107, but again matched well at Stations 142 and 184.

REPEATABILITY OF GRIT APPLICATIONS

Test	Grit	α, deg	β, deg	M_∞	Re_C, millions
— 7 x 10	Twin, #180	39.4	0.1	0.30	1.39
- - - LTPT	Twin, #180	40.0	0.0	0.30	1.41
o Flight	No grit	39.7	-0.3	0.25	9.57

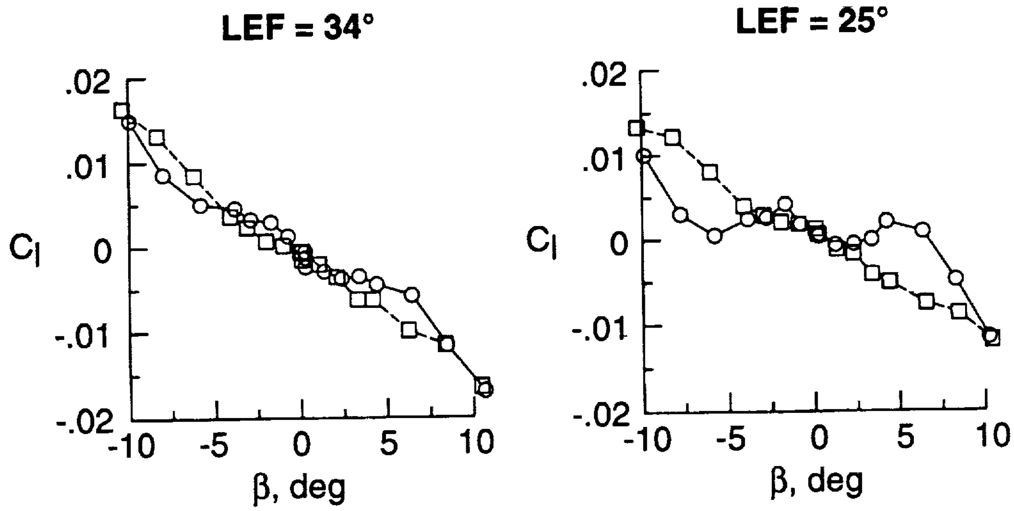


Assessing repeatability of grit applications

This figure compares the application of #180 grit in both the 7- by 10-Foot HST and the LTPT entry and correlates these data to flight. The agreement between these independent applications of grit is generally good. The areas of difference between the gritting occur for Station 107 near the leeside and involves apparently too large a vortex footprint for the LTPT gritting pattern. There are some differences in magnitude of the gritted pressure distributions on the leeside at Station 142. The large differences in the gritted patterns at Station 184 between 0° and 60° and 300° and 360° are due to linear extrapolation between data points. For the 7- by 10-Foot data, there are no points between 12° and 60° or between 300° and 348°. An additional entry of the forebody/shroud model in the 7- by 10-Foot HST during 1990 showed nearly identical results for gritting as well.

IMPACT OF FOREBODY GRITTING ON LATERAL CHARACTERISTICS

	Test	Grit	α, deg	M_∞	Re_C, millions
—o	7 x 10	Nose ring only	37.3	0.303	1.35
---□	7 x 10	Twin, #180	37.4	0.303	1.39



Gritting effects on lateral aerodynamic coefficients

Not only do the pressures change with the addition of the forebody gritting, but the lateral characteristics can be affected as well. Shown in the above figure are plots of rolling moment, C_l, as a function of β for the 7- by 10-Foot HST 6% high speed model entry. While the impact of gritting is small for the present flight leading-edge flap (LEF) deflection angle of 34°, the impact of gritting is significant for the 25° LEF deflection used by the prototype. It is also interesting to note that the presence of gritting does not appear to influence the values of C_l for $|\beta| < 3°$. Although not shown, the effects of gritting on yawing moment are small. While applying gritting enhanced static stability, other factors, such as the presence of a flight test nose boom, may have been responsible for the unpredicted departures, see reference 11.

SUMMARY OF CORRELATION IMPROVEMENT WITH GRITTING

- Reynolds number effects for smooth-sided forebodies are significant and can impact lateral characteristics

- Simulation of higher Reynolds number flows can greatly enhance ground test to flight correlations

- Test to test comparisons of high-α gritting applications have been good

Summary of correlation improvement with gritting

While high-α gritting patterns do not necessarily give perfect agreement over the entire forebody, they have the potential to greatly improve wind tunnel to flight correlations. This is crucial for vehicles with smooth-sided forebodies, where Reynolds number effects can significantly change the pressure distributions over the forebody and can impact lateral characteristics. As demonstrated by comparing two independent gritting applications on the same forebody but in two different tunnels, grit applications have acceptable repeatability. Just how grit is applied is important and excessive gritting, as discussed in reference 15, can lead to excessive normal loading and premature boundary-layer separation.

HATP EXPERIMENTAL AERODYNAMICS WORKING GROUP

- Identify key HATP data to be archived and key tunnel / flight correlations to be made
- Coordinate remainder of testing and analysis
- Determine if original wind tunnel / flight discrepancies can be addressed

HATP Experimental Aerodynamics Working Group

The charter of this working group, which functions under the direction of the HATP Steering Committee, is to identify important HATP data and to encourage that the data are archived and appropriately made available for key correlations. It has also coordinated current testing and analyses of the configuration aerodynamics data. The last charter of resolving the original wind tunnel to flight discrepancies is also being addressed. While resolving this issue is important, the first priority of the Working Group is to make sure that the community fully understands the more recent HATP data and the correlations between model-to-model, tunnel-to-tunnel, and tunnel-to-flight data that are now possible using models that reflect the current flight vehicle.

WORKING GROUP ACCOMPLISHMENTS AND STATUS

- Have identified significant HATP data bases and established points of contact

- Developing, in concert with the Steering Committee, a procedure for appropriate access to the data

- Will present a much more complete set of correlations between ground test and flight at the High-Alpha Conference in 1996

Working Group Accomplishments and Status

One the first tasks of the Working Group members was to summarize the significant HATP-related experiments that have occurred. Within this summary, descriptive information is included with regard to test objectives, configurations tested, and points of contact. The Working Group has also served to increase communication between the Centers and has helped to coordinate the remainder of the testing and analyses. An important issue is the need of industry for ready access to the data. This question has been discussed and the current status is that a request for data will be filtered through the respective Center's Steering Committee member for approval of the data release. Of course, providing a summary of final correlations between tunnel-to-flight, tunnel-to-tunnel, and model-to-model is a main objective for the High-α Conference in 1996.

CLOSE-OUT TESTING PLANNED AT LANGLEY

- Objectives
  - Assess ground test to flight differences with and without gritting
  - Assess tunnel-to-tunnel differences
  - Assess model-to-model differences
- 30- by 60-Foot Tunnel of 16% low speed model
  - Pressures on forebody, LEX, and over wing
  - Leading edge flap deflections and gritting patterns
- 14- by 22-Foot Subsonic Tunnel test of both 16% low speed and 6% high speed models
  - Pressures on forebody and LEX for 6% model
  - Pressures on forebody, LEX and over wing for 16% model
  - Leading edge flap deflections and gritting patterns

Close-out testing planned at Langley

Two test entries are currently planned for later this year. The first entry involves testing the low speed 16% model in the Langley 30- by 60-Foot Tunnel. The key objective for this test is to measure pressures and determine lateral/directional characteristics at low values of dynamic pressure. High-α gritting studies will also be performed. A second entry at Langley will occur in the 14- by 22-Foot Subsonic Tunnel. This entry will also test the same low speed 16% model with and without grit to evaluate tunnel-to-tunnel differences. Also during the 14- by 22-Foot entry, the 6% NAVAIR/McDonnell Douglas high speed model will be tested with and without grit to evaluate model-to-model differences in the same facility.

SUMMARY - WORKING GROUP

- Monitoring final experimental activities of HATP configuration aero work

- Working Group is open to feedback from the user community

Summary–Working Group

The HATP Experimental Aerodynamics Working Group is monitoring the final experimental activities concerning configuration aerodynamics. If the user community has any feedback concerning the experimental program or about correlations, please contact any member of the Working Group. Member names and telephone numbers are listed below.

Robert M. Hall, NASA-Langley, 804-864-2883, Chairman
Daniel W. Banks, NASA-Langley, 804-864-5067
David F. Fisher, NASA-Dryden, 805-258-3705
Farhad Ghaffari, NASA-Langley, 804-864-2856
Daniel G. Murri, NASA-Langley, 804-864-1160
James C. Ross, NASA-Ames, 415-604-6722

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