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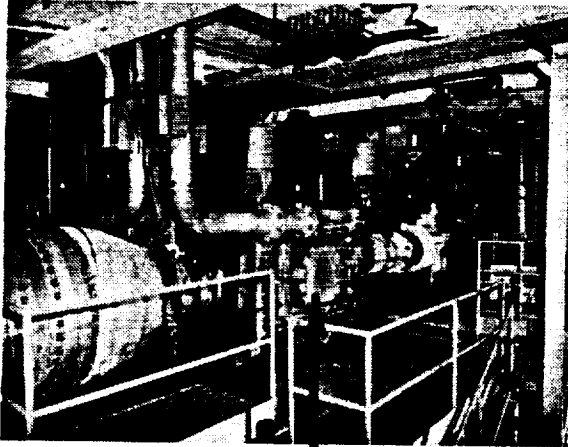
**AN EXPERIMENTAL AWTS PROCESS  
AND  
COMPARISONS OF ONERA T2 AND 0.3-M TCT AWTS DATA  
FOR THE ONERA CAST-10 AEROFOIL**

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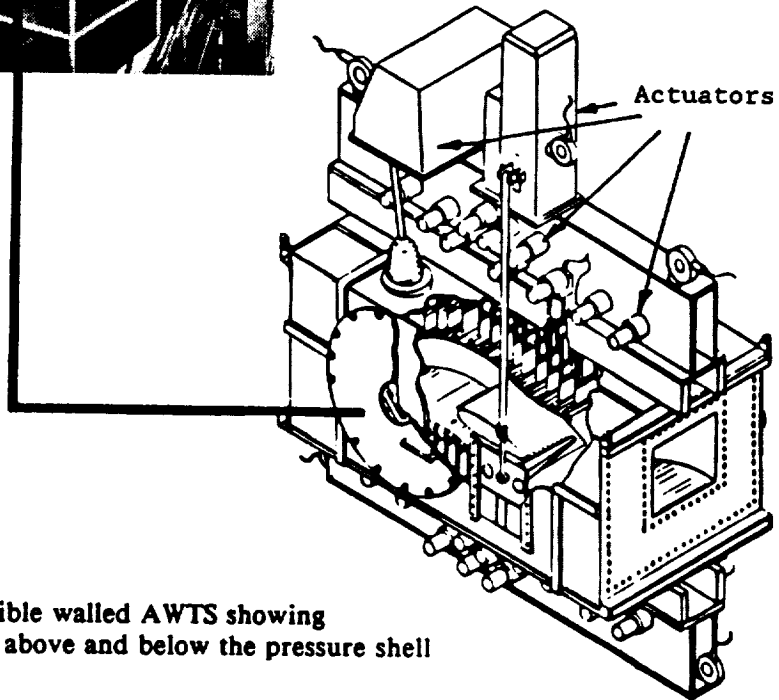
**and**

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NASA Langley Research Center**

### NASA Langley 0.3-m TCT



Flexible walled AWTS  
installed in the 0.3-m TCT



Sketch of flexible walled AWTS showing  
jack actuators above and below the pressure shell

## **EXPERIMENTAL AWTS PROCESS IN THE 0.3-m TCT**

**Test Section Design** - Four solid walls, floor and ceiling adjustable.  
Total of 21 wall jacks per wall (note only 18 wall jacks used in wall adjustment process).

**Wall Adjustment Process** - Fast and iterative, based on wall data only.  
Judd method with linearized compressible flow theory (2-D testing only).

**Wall Data** - Ceiling and floor jack positions.  
Ceiling and floor pressures on the tunnel centerline.

We began operating the NASA Langley 0.3-m TCT (Transonic Cryogenic Tunnel) with an Adaptive Wall Test Section (AWTS) in March 1986.<sup>1</sup> The AWTS has a 33 cm (13 inch) square cross-section with four solid walls. The floor and ceiling are adjustable. We control the wall shapes with a system of 21 computer controlled jacks. We use only 18 jacks per wall in the wall adjustment process. The 3 downstream jacks simply control a variable diffuser to provide a smooth interface between the AWTS and the rigid tunnel circuit.

The wall adjustment process is both fast and iterative and requires only information on the flexible walls. The theory of the process utilizes the well-proven Judd method using linearized theory.<sup>2</sup>

We obtain the wall data for the wall adjustment process and residual interference assessment simply by measuring the jack positions and the wall pressures on the tunnel centerline.

## **QUALITY OF WALL ADJUSTMENTS / STREAMLINING**

### **Assessment of Residual Wall Interferences**

**Input data - Measured and calculated wall pressures.  
Aerodynamic position of floor and ceiling.  
Position of model chordline in the AWTS.**

#### **Empirical Maxima -**

- 1) Average  $C_p$  error (between streamline and measured values) along each wall - 0.01
- 2) Induced angle of attack at the model leading edge -  $0.015^\circ$
- 3) Induced camber along the model chordline -  $0.07^\circ$
- 4) Average induced streamwise  $C_p$  error along the model chordline - 0.007

We assess the quality of the wall adjustments/streamlining by calculating the residual wall interferences due to the floor and ceiling. The calculations are quick (allowing real-time use) using linearized compressible flow theory with the input data listed above.

The wall adjustment process automatically stops when all the residual wall interferences reduce below the maxima listed above. These maxima are defined empirically as a compromise between perfection (zero residual wall interferences) and unnecessary iterations of the wall adjustment process. These maxima are related to the quality of the AWTS hardware and instrumentation and stability of test conditions in the AWTS.

We do not apply any of these residual wall interference corrections to the final aerofoil data. We consider the real-time aerofoil data to be "corrected." In this adaptive wall context, "corrected" refers to the elimination of wall interferences at the source of these interferences.

## COMPARISONS OF T2 AND 0.3-m TCT AEROFOIL DATA

### Comparison Qualifications

- Most of 0.3-m TCT data is new and preliminary.
- Concentration on data at the design Mach number.
- No sidewall boundary layer control involved.
- Similar testing techniques in T2 and 0.3-m TCT.
- No conclusions given to bias the workshop discussions.

Before we present any data comparisons, it should be known that the above qualifications apply to the comparisons. Most of the 0.3-m TCT data presented here is new and unpublished and must therefore be considered as preliminary. This new data comes from a re-test (T-224) of the ONERA CAST 10 carried out in August 1988. (Original 0.3-m TCT data came from tests T-212 and T-216.) We found it necessary to carry out this re-test due to discrepancies in the 0.3-m TCT data from the two CAST 10 models. We will not discuss these discrepancies here.

We concentrate the data comparisons on the design Mach number 0.765 because of the known sensitivity of the CAST 10 section at this Mach number. This sensitive situation acts as an excellent challenge for free air simulations.

We did not use sidewall boundary layer control during the 0.3-m TCT tests nor did the French in their tests.

The ONERA/CERT T2 tunnel and the 0.3-m TCT use similar testing techniques. Both tunnels have flexible walled AWTS's. We do not discuss the French wall adjustment process here. Suffice to say, the process is well established at ONERA and is similar to the NASA process. However the T2 wall adjustment process does not involve any residual wall interference assessment due to the intermittent tunnel operation. Interestingly, we did attempt to use the T2 wall adjustment process with the 0.3-m TCT but failed to achieve a converged solution due mainly to software problems.

We do not give any conclusions in this presentation to bias any discussion of these data comparisons. We present these data comparisons with comments as input for the forthcoming workshop discussions.

## TESTING FACTS

- Aerofoil Chord - 18 cm (7.09 inches)
- Test Section Height/Chord Ratio - 1.83 (0.3-m TCT) & 2.05 (T2)
- Aspect Ratio - 1.833 (0.3-m TCT) & 2.166 (T2)
- Transition Location on both surfaces - 6% (0.3-m TCT) & 5% (T2)
- Transition Strip - 1.7% of 0.053/0.043mm dia. micro-spheres (0.3-m TCT)  
0.045mm high carborundum grit (T2)
- Mach Number Stability - 0.002 (0.3-m TCT) & 0.004 (T2)
- Data Shortfall - Sparsity of high Reynolds number data from T2

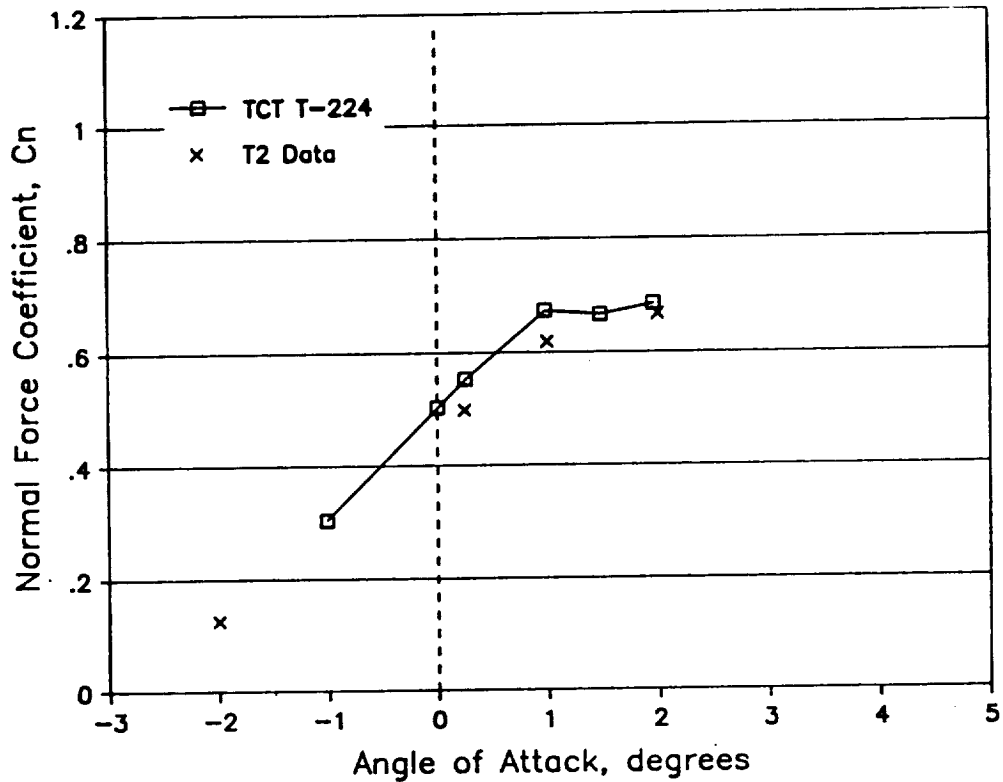
The testing facts listed above define the model condition for the data compared here. The transition strip location in the NASA tests is a compromise between the ONERA and DFVLR locations.

Mach number stability during a polar is a problem in the T2 tunnel because each data point is a separate run of this intermittent tunnel. The 0.3-m TCT is a continuously operating tunnel.

The T2 data we used here is not complete. There is a sparsity of high Reynolds number data for example. This incompleteness makes it very difficult to make more meaningful direct comparisons than shown here.

# ONERA CAST 10 Aerofoil Data

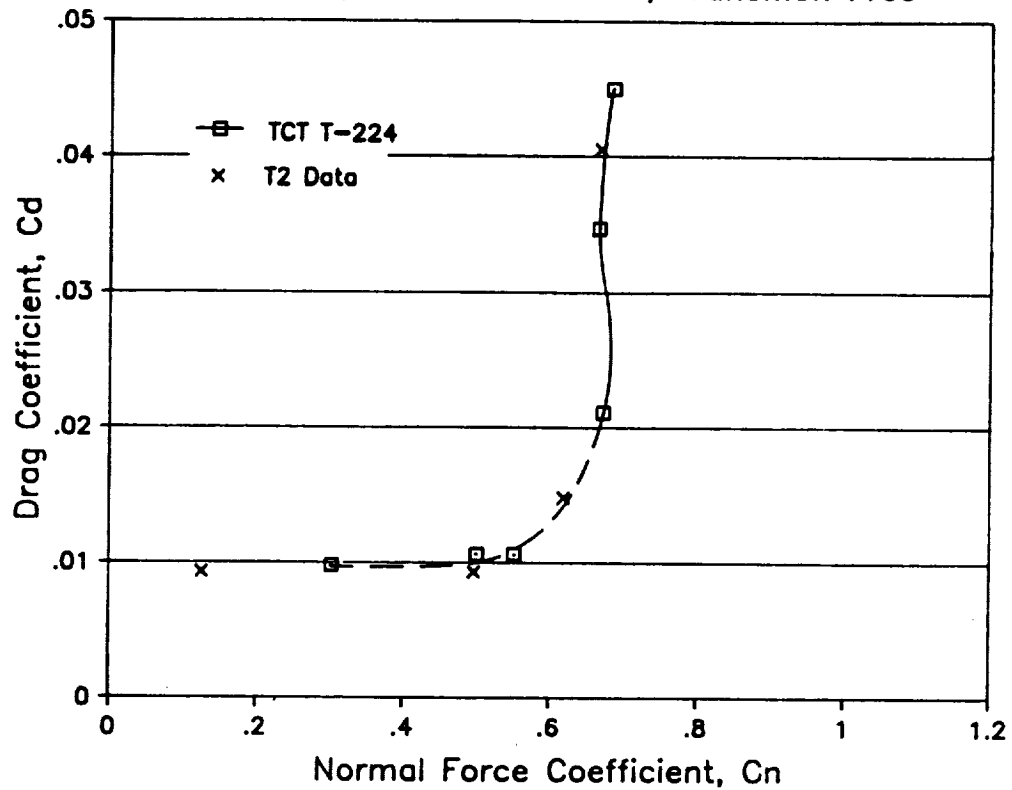
Mach = 0.765 ;  $R_c = 21$  million ; Transition Free



This data comparison is for the test conditions Mach 0.765, 21 million chord Reynolds number, and transition free. The  $C_n$ - $v$ - $\alpha$  data shown above indicates an  $\alpha$  difference between the two tunnels. It seems as though  $C_{n_{max}}$  is matched but the sparsity of T2 data does add some uncertainty. The range of Mach number in the four T2 data points is 0.007, compared with 0.0003 in the 0.3-m TCT data.

# ONERA CAST 10 Aerofoil Data

Mach = 0.765 ;  $Re_c = 21$  million ; Transition Free

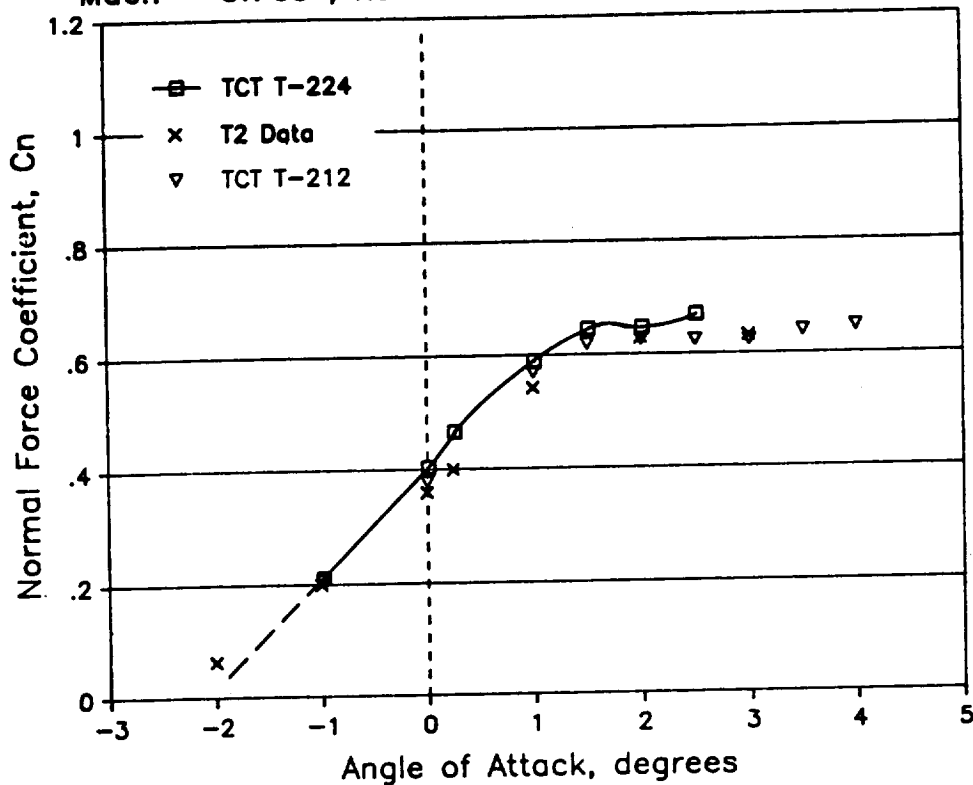


Continuing the data comparison at 21 million chord Reynolds number. The graph of  $C_d$ -v- $C_n$  shows a remarkably good data comparison. This confirms that there is an  $\alpha$  difference between the two tunnels. The repeatability of data on a known sensitive aerofoil is always a challenge. Add to this challenge, tests in different tunnels with natural transition and you have the very demanding situation discussed here.



## ONERA CAST 10 Aerofoil Data

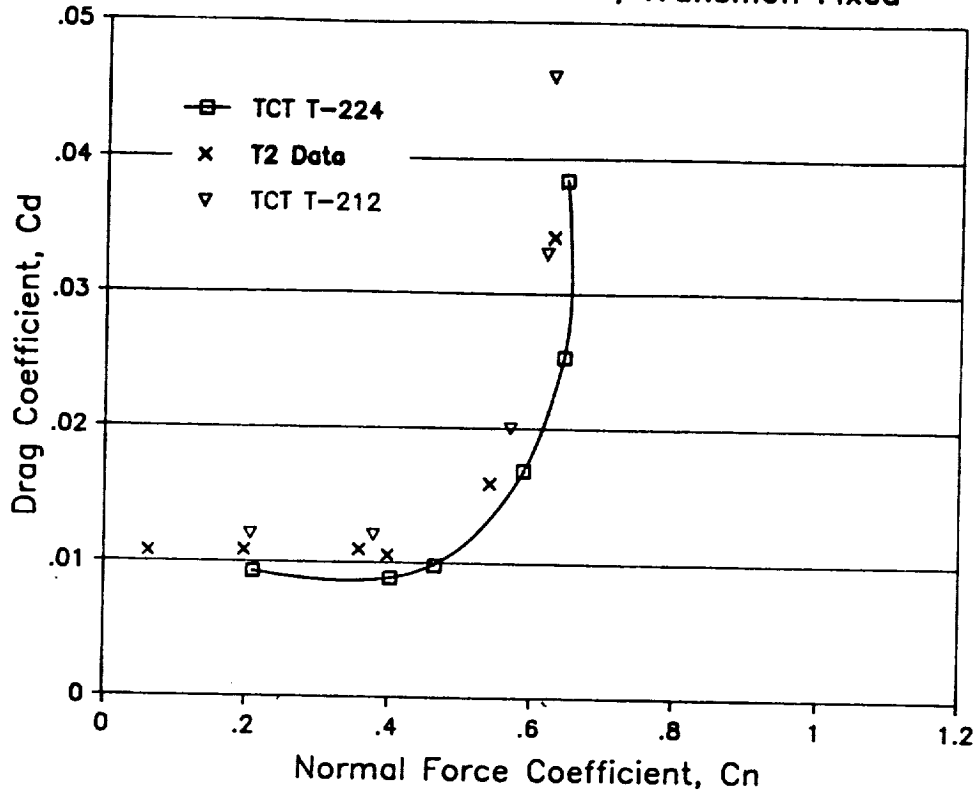
Mach = 0.765 ;  $R_c = 4$  million ; Transition Fixed



If we now reduce the chord Reynolds number in the data comparison to 4 million, we find much more T2 data. The  $C_n$ - $v$ - $\alpha$  data again indicates that there is an  $\alpha$  difference persisting between the two tunnels. We have more confidence in the matching of  $C_{n_{max}}$  at this lower Reynolds number. We include the original 0.3-m TCT data set (T-212) in this comparison to show data repeatability. Notice the latest set (T-224) has slightly higher  $C_n$  values. Nevertheless, both sets of 0.3-m TCT data show a higher lift curve slope than found in T2.

# ONERA CAST 10 Aerofoil Data

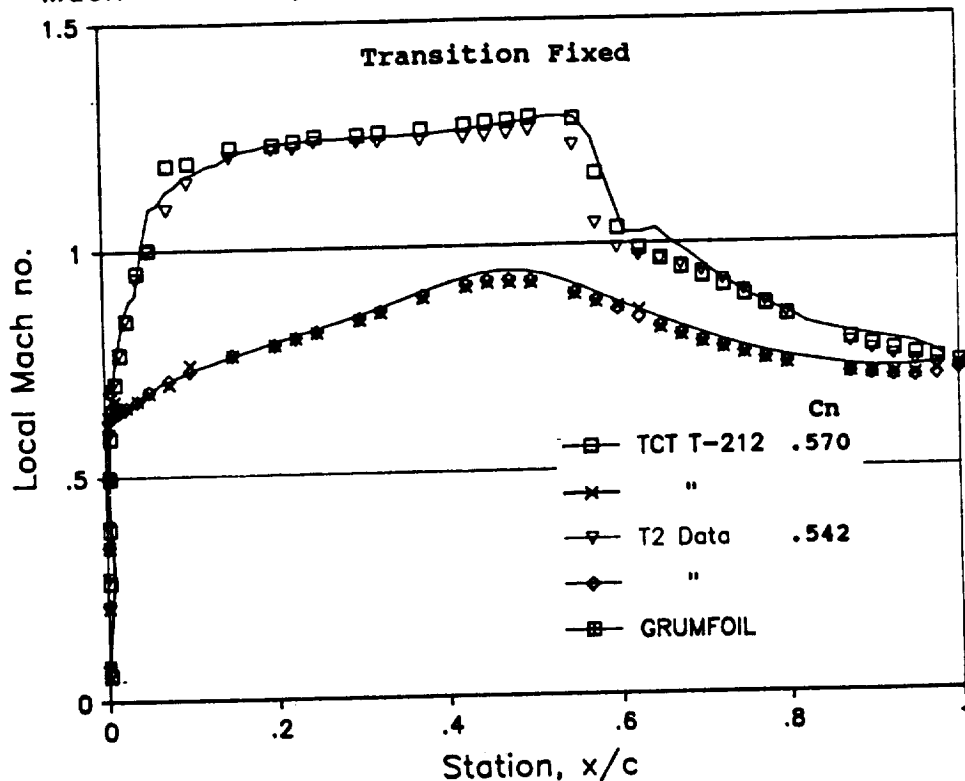
Mach = 0.765 ;  $R_c = 4$  million ; Transition Fixed



When we remove  $\alpha$  from the 4 million Reynolds number data, we see another source of data differences. In the  $C_d$ -v- $C_n$  graph shown above, we see that the two 0.3-m TCT data sets bracket the T2 data in terms of  $C_{d_{min}}$  and  $C_{n_{max}}$ . It is clear that the transition fixing is significantly affecting lift and drag. This highlights one of the major problems of simulating scale effects. The what, where and how much of transition fixing remains a big question. Another factor we must consider is the improved tunnel control system for the latest 0.3-m TCT test (T-224). We have more confidence in the drag from the latest tests.

# ONERA CAST 10 Aerofoil Data

Mach = 0.765 ; Rc = 4 million ; Alpha = 1 degree

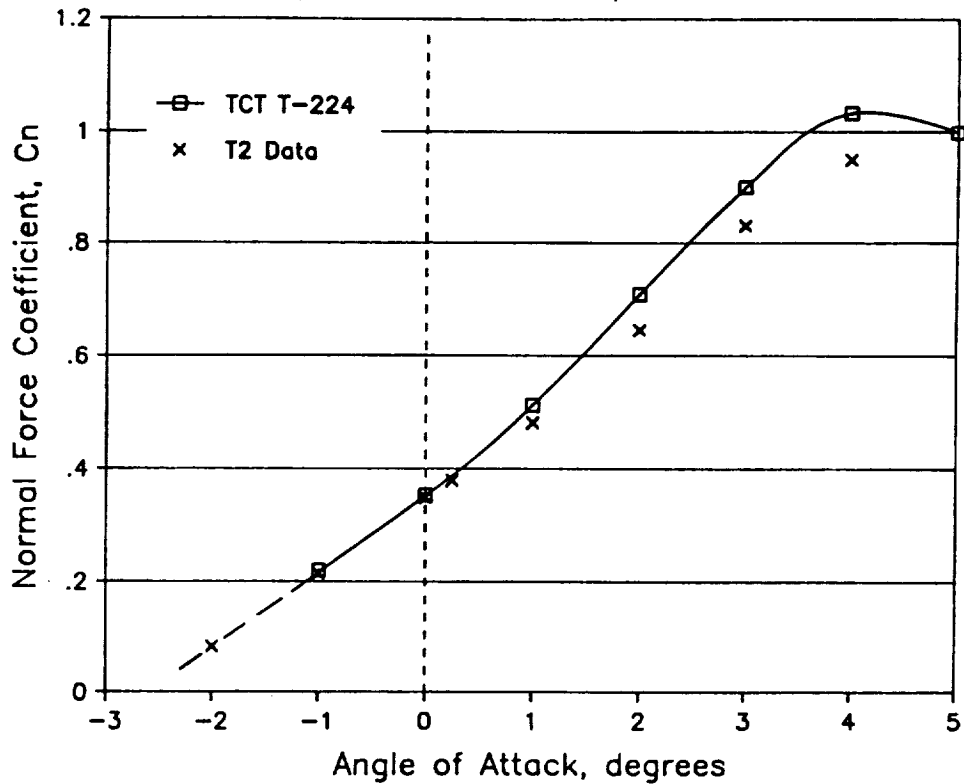


The comparison of detailed pressure distributions on the aerofoil are difficult. This is because the normal force was not matched between the two tunnels at lifting conditions. However, it is interesting to make a data comparison at  $\alpha = 1^\circ$  and Mach 0.765, with transition fixed, as shown above. This is a challenging test condition with near maximum lift. The comparison is good with notable differences near the leading edge (due to the transition strip) and at the shock location. The movement of the shock is small, of the order of the pressure tap spacing (2.5% of chord).

We also include a GRUMFOIL free air solution in this comparison. The normal force of the GRUMFOIL result is matched to that of the 0.3-m TCT data. The comparison is very good. Incidentally, other comparisons with GRUMFOIL have been made which are also good provided  $C_n$  is less than  $C_{n_{max}}$  and the transition location on the aerofoil is known.

# ONERA CAST 10 Aerofoil Data

Mach = 0.7 ;  $R_c = 3.7$  million ; Transition Fixed

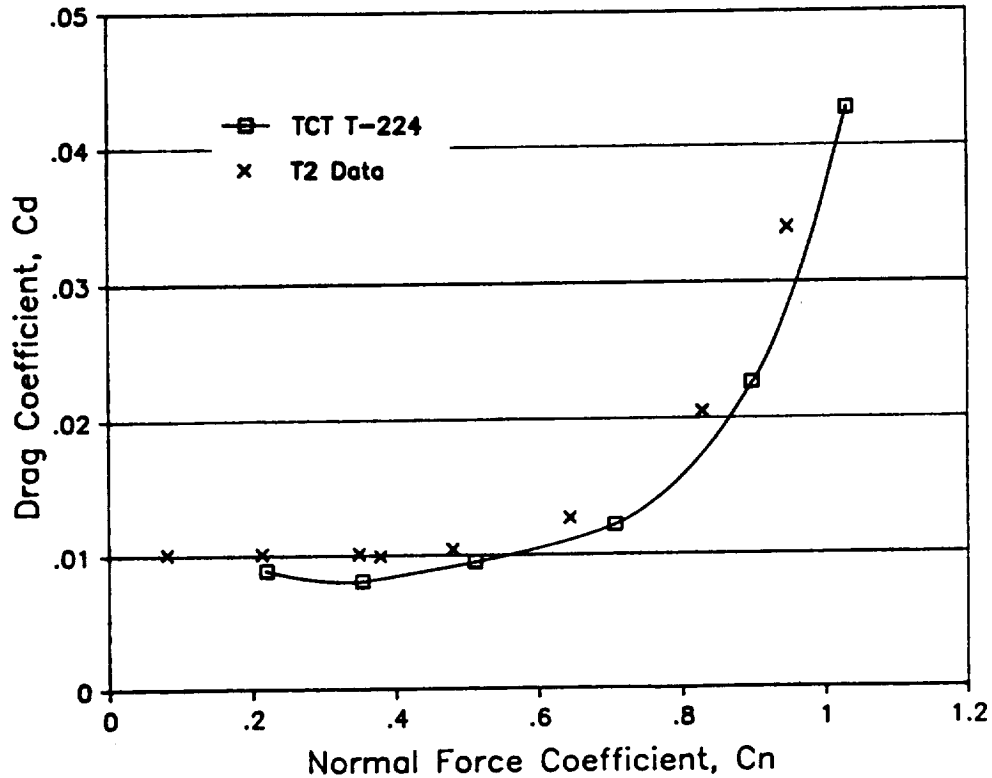


So far we have compared data at only the design Mach number. If we examine data at Mach 0.7 we see a similar trend in the  $C_n$ - $v$ - $\alpha$  graph shown above. Again there is the same  $\alpha$  difference between the two tunnels as seen at higher Mach number and Reynolds number. Unfortunately, we believe that  $C_{n_{max}}$  could not be obtained in the T2 tunnel at Mach 0.7, due to limitations to the flexible wall movement in the T2 AWTS. The 3.7 million chord Reynolds number of this data coincides with the majority of T2 tests at Mach 0.7.

Unfortunately, very little T2 data exists above Mach 0.765, so no data comparisons are possible for Mach numbers higher than the design value.

## ONERA CAST 10 Aerofoil Data

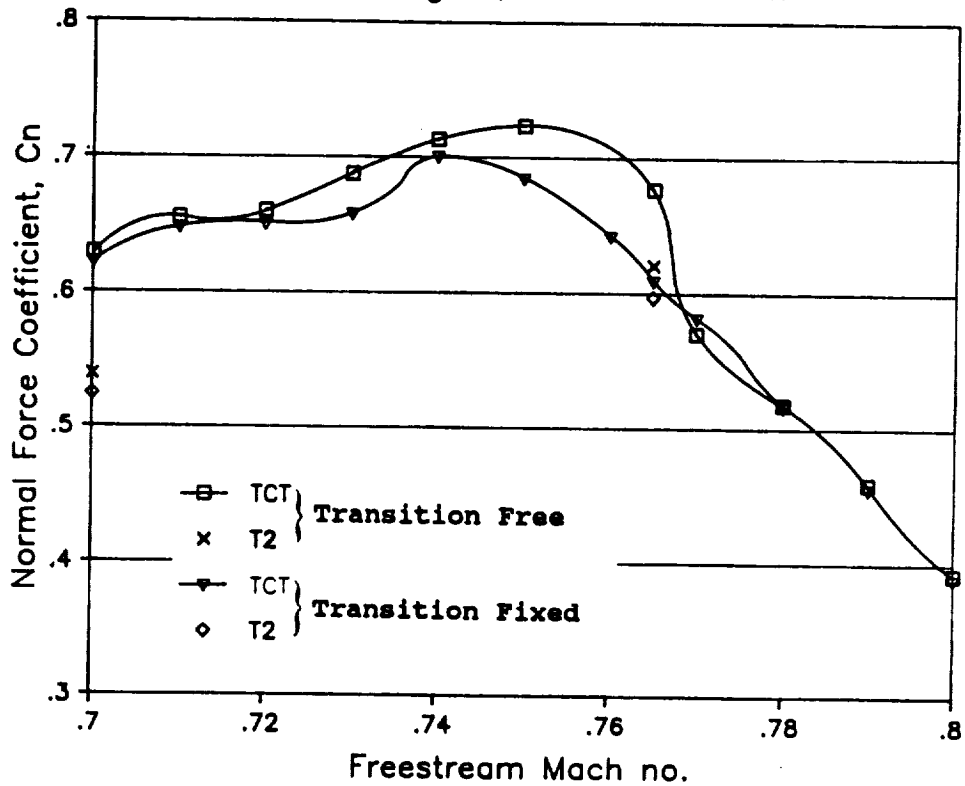
Mach = 0.7 ;  $R_c = 3.7$  million ; Transition Fixed



The  $C_d$ -v- $C_n$  data at Mach 0.7 and 3.7 million chord Reynolds number shows a similar comparison as found at Mach 0.765. Once again the 0.3-m TCT data has lower drag than the T2 data by about 20 drag counts. This drag difference is due to the state of the transition fixing. The French grit is thicker than the NASA Micro-Spheres in this case.

# ONERA CAST 10 Aerofoil Data

Alpha = 1 degree; Rc = 20 million

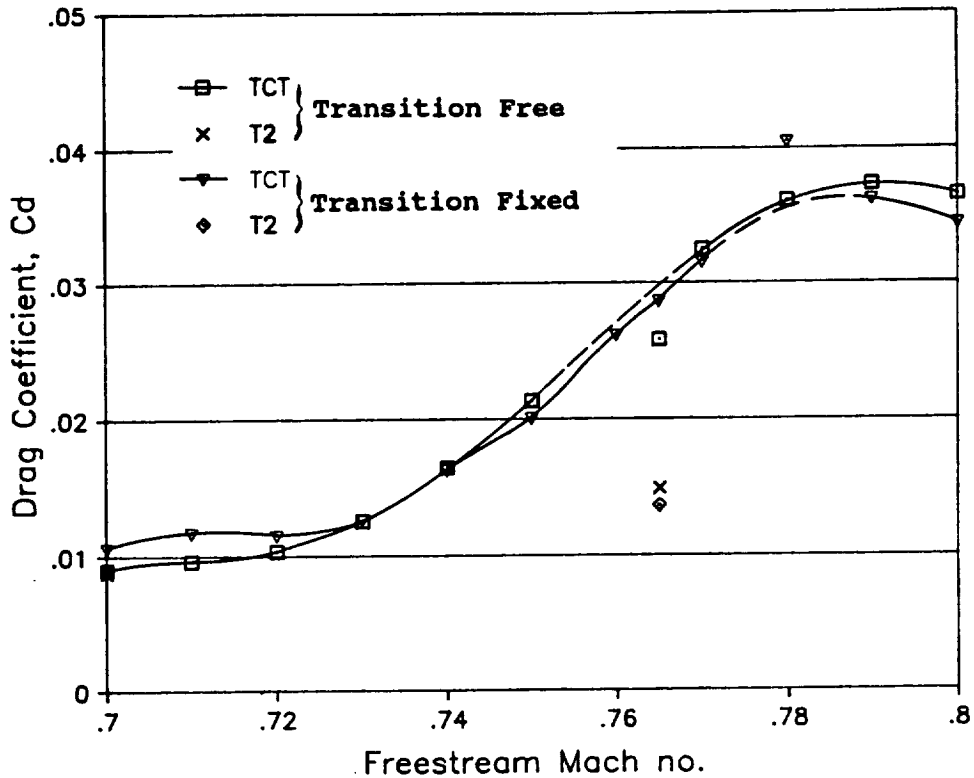


Let us now examine the effect of Mach number at a fixed  $\alpha$ . We choose to look at data at 20 million chord Reynolds number where we expect the effects of transition fixing to be minimal. A plot of  $C_n$ -v-Mach number is shown above over the Mach number range 0.7 to 0.8. Notice the shock stall in the 0.3-m TCT data (from T-216) occurs at about Mach 0.74 transition fixed and about Mach 0.75 transition free. There is insufficient T2 data to see shock stall, but what we can see is a minimal effect of transition fixing. This indicates that the T2 transition fixing was well scaled for 20 million chord Reynolds number.

At the design Mach number, the 0.3-m TCT data indicates that  $C_n$  is very sensitive to transition fixing and Mach number at this high lift condition.

# ONERA CAST 10 Aerofoil Data

Alpha = 1 degree; Rc = 20 million

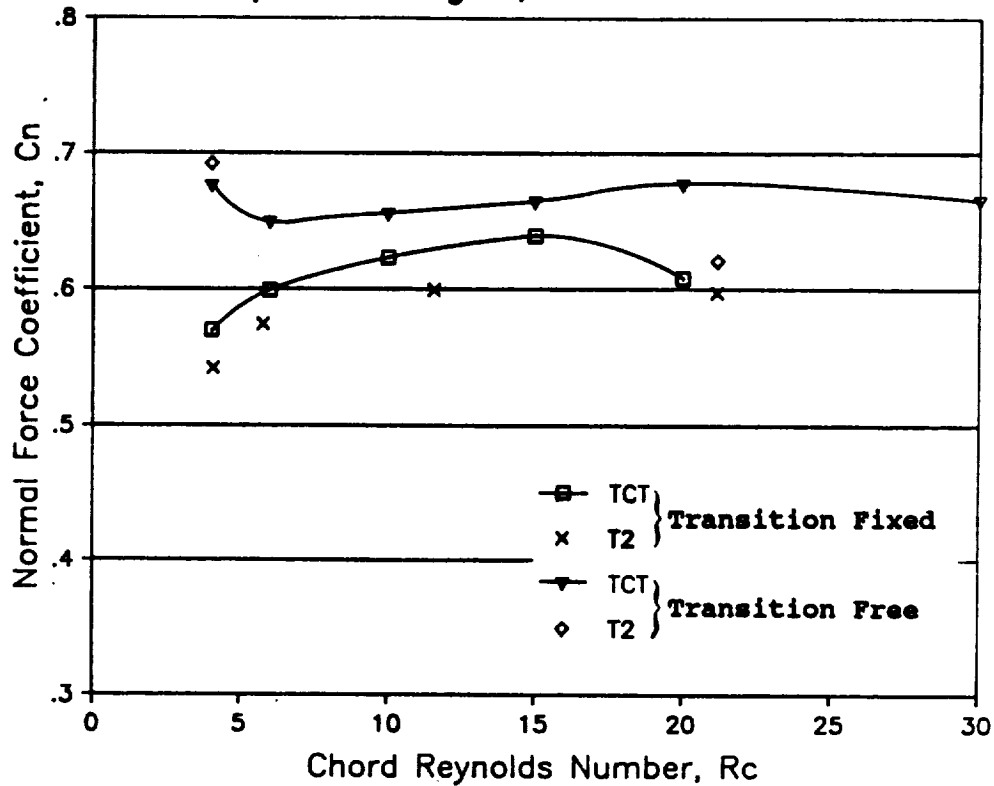


We now look at how the drag coefficient,  $C_d$ , varies with Mach number for the same conditions as shown in the previous figure. We see that the effect of transition on the 0.3-m TCT data is as small as found in the limited T2 data. The 0.3-m TCT data are faired to remove some clearly wayward data points. We attribute this scatter to the less than perfect tunnel control system used in the initial 0.3-m TCT tests (T-216).

We see that the T2 drag at Mach 0.765 is significantly lower than the 0.3-m TCT value. This seems to indicate that the effective  $\alpha$  of the T2 data is lower than the geometrical  $\alpha$ .

## ONERA CAST 10 Aerofoil Data

Alpha = 1 degree; Mach = 0.765



We consider Reynolds number effects at the same  $\alpha$  of  $1^\circ$  using 0.3-m TCT data from the initial test (T-212). The plot of  $C_n$ -v- $R_c$  shown above is for the chord Reynolds number range from 4 million to 21.2 million with transition fixed. We can observe that the effect of transition fixing as Reynolds number increases is not straightforward. Meanwhile, data comparisons at a lower  $\alpha$  of  $0.25^\circ$  show that the effect of transition fixing reduces as Reynolds number increases, as expected.

However, we can see that the transition free data from the 0.3-m TCT shows a small Reynolds number effect concentrated between 4 and 6 million. With transition fixed, the Reynolds number effects are larger and occur over the entire Reynolds number range investigated.

The limited T2 data shows that there is minimal transition effect at 21 million chord Reynolds number, again pointing to good sizing of the transition grit for high Reynolds number testing.

The Reynolds number effects are small compared with Mach number effects. However, we can see that incorrect transition fixing can have serious consequences.



## SUMMARY OF FINDINGS

Remarkable data agreement with the limited high Reynolds data from T2.

Angle of attack difference between the two tunnels.

Drag differences at low Reynolds number.

Good agreement with free air GRUMFOIL code, below  $C_{n_{max}}$ .

More T2 data required to confirm some observations.

### References

1. Wolf, S. W. D.; and Ray, E. J.: **Highlights of Experience with a Flexible Walled Test Section in the NASA Langley 0.3-Meter Transonic Cryogenic Tunnel.** AIAA Paper 88-2036. Presented at the AIAA 15th Aerodynamic Testing Conference, San Diego, CA, May 18-20, 1988.
2. Wolf, S. W. D.; and Goodyer, M. J.: **Predictive Wall Adjustment Strategy for Two-Dimensional Flexible Walled Adaptive Wind Tunnel. A Detailed Description of the First One-Step Method.** NASA CR-181635, January 1988, N88-19409#.

