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Design and Construction of Two Transonic Airfoil Models for Tests in the NASA Langley 0.3-M TCT

by

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Summary: As part of a NASA/DFVLR cooperative program two transonic airfoils were tested in the NASA 0.3-Meter Transonic Cryogenic Tunnel. The design and construction of the models was, guided by NASA experiecence, carried out by DFVLR. The present paper mainly covers matters related to model design and construction. This is supplemented by some aerodynamic test results.

1. INTRODUCTION

Recognizing the need for high Reynolds number research at transonic speeds and realizing that high Reynolds numbers are most practicably be obtained by low temperatures, a cooperative program with NASA Langley was initiated testing two transonic airfoils, viz., the Dornier design CAST 10-2/DOA2 and the DFVLR-R4 in the Langley 0.3-Meter Transonic Cryogenic Tunnel. Specific objectives were

- to gain experience in model design, fabrication and testing under cryogenic conditions
- to determine the Reynolds number dependence of the flow development on a special class of transonic airfoils and
- to correlate 0.3-M TCT results with results from other major two-dimensional test facilities.

In accordance with the first objective, the model design and construction was, guided by NASA experience, carried out by DFVLR.

This contribution mainly covers matters related to model design and construction. However, as supplement, some aerodynamic test results demonstrating the Reynolds number sensitivity of one of the airfoils investigated and comparing TCT-data with results from other facilities are given.

2. MODEL DESIGN AND CONSTRUCTION

For the first time the Technical Services Göttingen of the DFVLR were requested to design and fabricate an airfoil model equipped with a large number of pressure orifices for tests under cryogenic conditions. As a first step all available information about experiences in the construction of models for cryogenic temperatures and the requirements to be met by such models were gathered - with one of the major sources, of course, being the people at NASA Langley. One of the main questions concerned the way in which two model halfs could be joined since any connection with access through the upper or lower surface was ruled out. After some pre-tests with bonding failed, it was decided to braze the model components.

Various manufacturing pre-tests lead to a work plan to which the sequence of model construction had to adhere. The construction was accompanied by frequent checks to avoid geometry deviations beyond repair. After model completion a final check of the surface contour was carried out on a ZEISS precision gaging machine at DFVLR Braunschweig. The only manufacturing process not carried out at DFVLR was the brazing which was done, after expert counsel by DEGUSSA concerning the silver solder to be used, by DANNER Schutzgastechnik und Apparatebau GmbH. who specialize in brazing under protective atmosphere.

2.1 MODEL DESIGN

Model design features and pre-tests are summarized in the following viewgraphs.

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MODEL DESIGN REQUIREMENTS

1. A total of 90 pressure orifices distributed in two chordwise and one spanwise row.
2. Pressure orifices must be drilled into the surface, i.e., the pressure tubes must not come to the surface.
   Hole diameter 0.3 mm (0.012 inch).
3. Channels for pressure tubes must be as narrow (height and width) as possible to get maximum bending resistance.
4. Establish coordinates of all drill holes in order to be able to drill pressure orifices into the surface.
5. Provide for special orifices in the nose and trailing edge. Orifices should not influence each other.
6. Locate the soldering plane near the neutral bending zone so that there is essentially no shear stress in the soldering layer.
7. Main dimensions of the air-foil-model.

span	202.69	(8 in)		
chord length	151.40	(6.0)		
thickness	18.61	(0.73)	(10-2)	12 %
	20.49	(0.80)	(R4)	13.5 %.

8. Design must meet soldering requirements, i.e., allow for soldering gaps, solder deposits, gas-channels, flow direction of the solder.
9. No screw connections.

CHOICE OF MATERIAL

1. Stainless steel.

2. No embrittling and loss of toughness at cryogenic temperatures.

3. Little or no warping.

4. Good wettability with silver solder.

5. Surface able to be burnished and polished at the buff wheel.

6. No embrittling after soldering-heat-treatment.

7. Safty factor against 0.2 % yield, 3 or more; safety factor against ultimate 4 or more.

MODEL MATERIAL PROPERTIES

1. Material selected

St 1.4301, AISI Type 304, SAE 30 304
1.6900 (type for cryogenic use)

Cr = 18 % typical
N = 9 % typical
C = 0.07 % max.
Si = 1.0 % max.
Ma = 2.0 % max.

2. Mechanical properties at ambient temperatures

0.2 % yield strength	minimum 185 N/mm^2
at 78 K	≈ 300 N/mm^2
ultimate strength	minimum 500-700 N/mm^2
at 78 K	≈ 1180 N/mm^2
Impact:	
DVM-sample	85 J
	12 kpm/cm^2
at 78° K	8 kpm/cm^2

3. Physical property

Thermal expansion 0.28 %
between 293 and 80 K

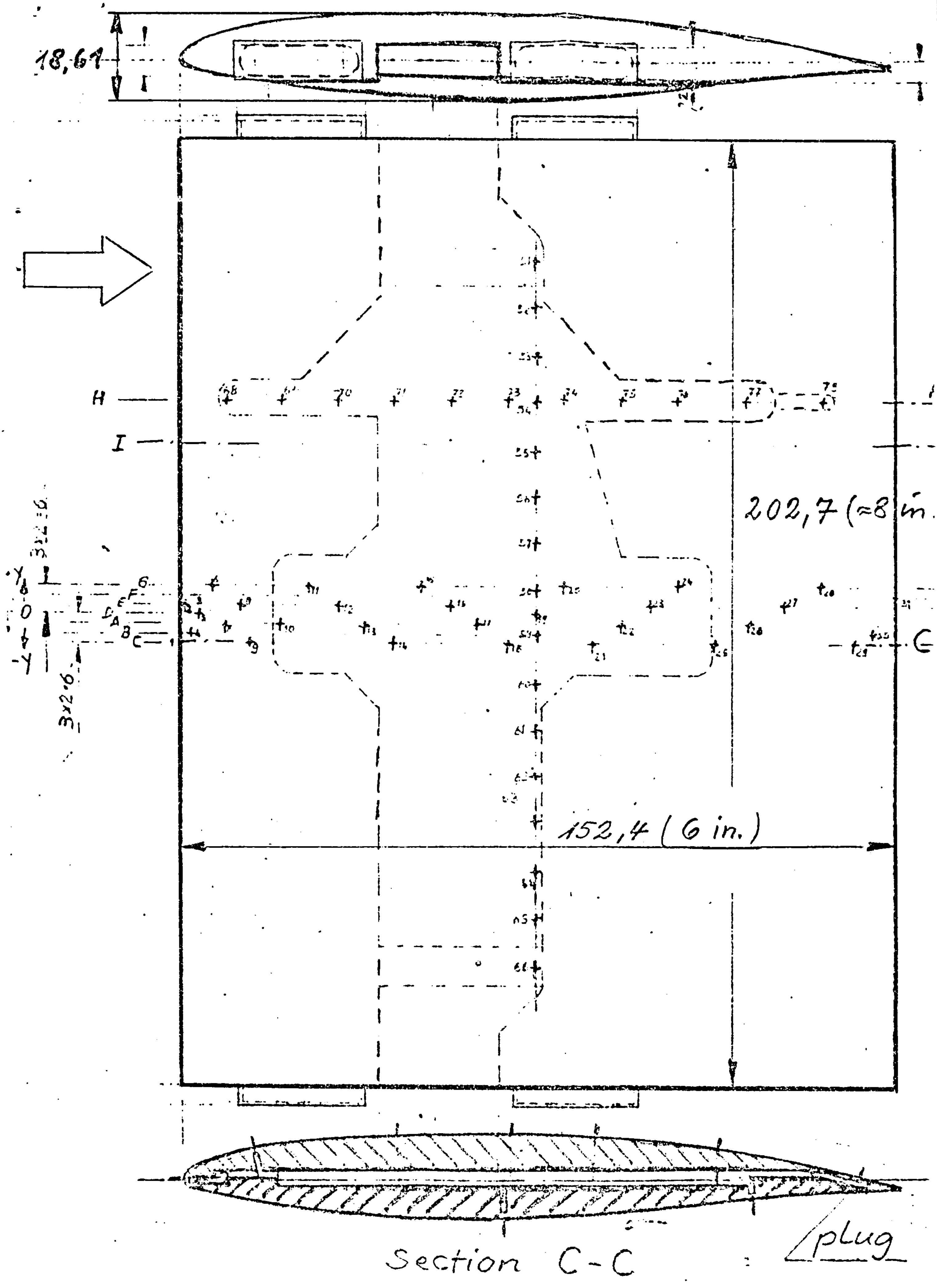
4. Silver solder:

Degussa 7200 DIN 8513 L-Ag 72, 2.5151, ASM-ASTM BAg-8.

Ag = 72 %
Cu = 28 %.

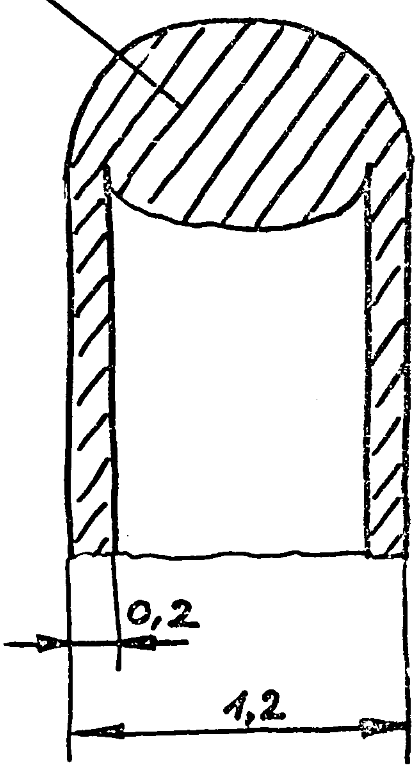
Working temperature	1053 K
Temperature used	1393 K

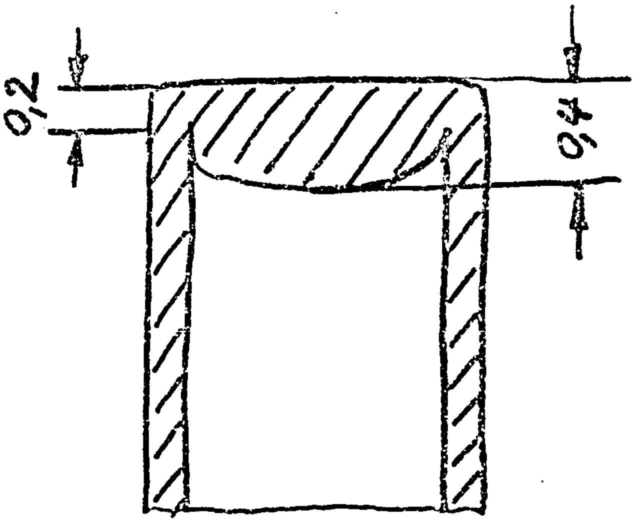
Note: Same silver solder was used for soldering pressure tubes inside model and brazing model halfes.


18,61
H
I
202,7 (≈8 in.
152,4 (6 in.)
Y
0
-Y
3x2.6
A
B
C
D
E
F
C
Section C-C
plug

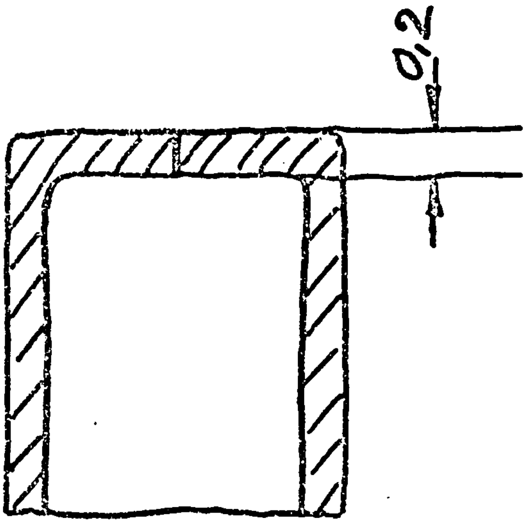
Preparation of the tube ends to be silver-soldered to the inside of the model halfs

welded on a thermocouple welding machine





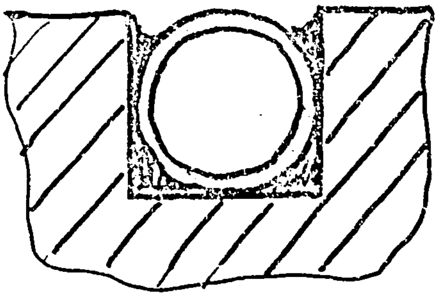
Turned down to 0,4 mm



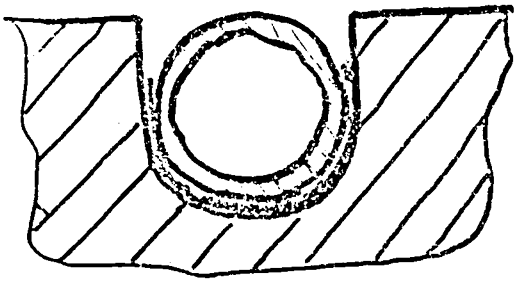
End of tube chased in the lathe

all tubes are checked for leaks at 10^{-4} bar

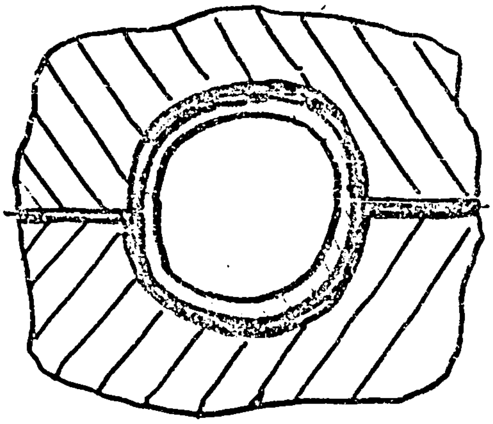
Test solderings to imbed the pressure tubes inside the model



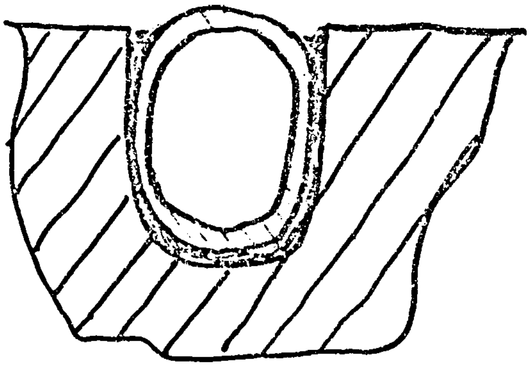
Keeps much silver solder in the corners. Less good.



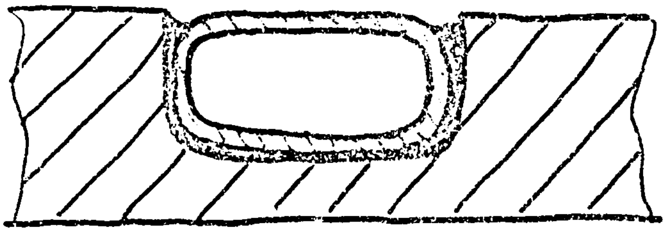
For good soldering. Requires less solder.



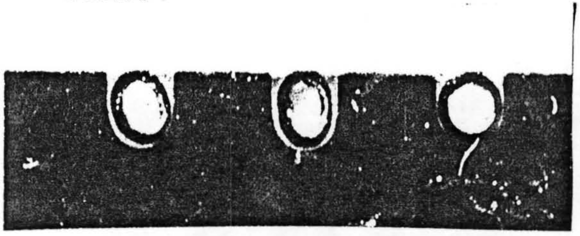
For thin profiles. Grooves on both halfs should fit together.

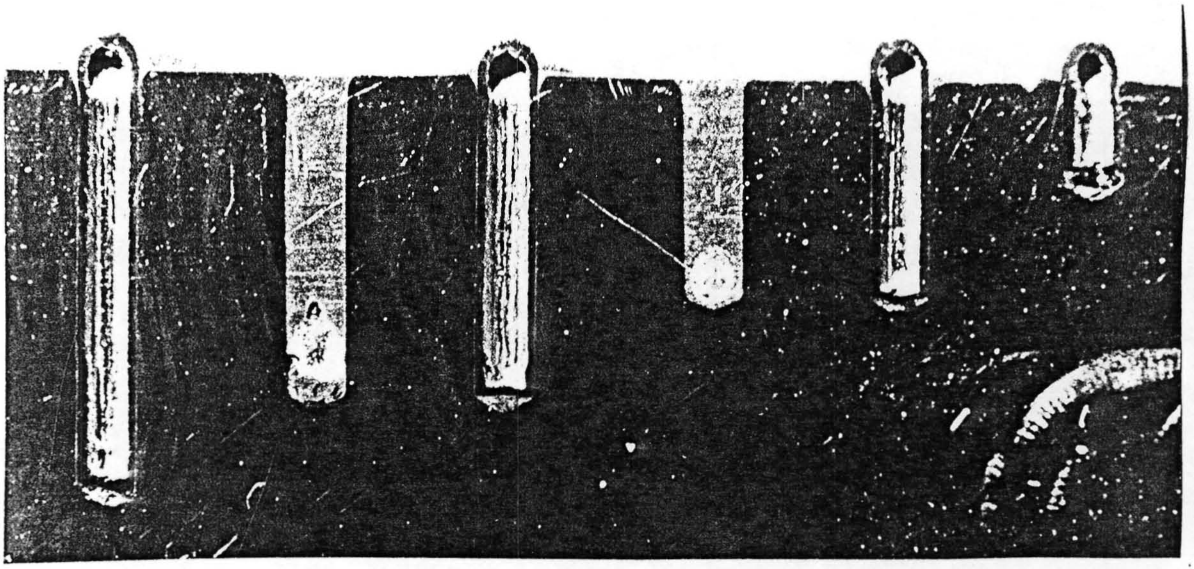


For narrow grooves. Requires less width.

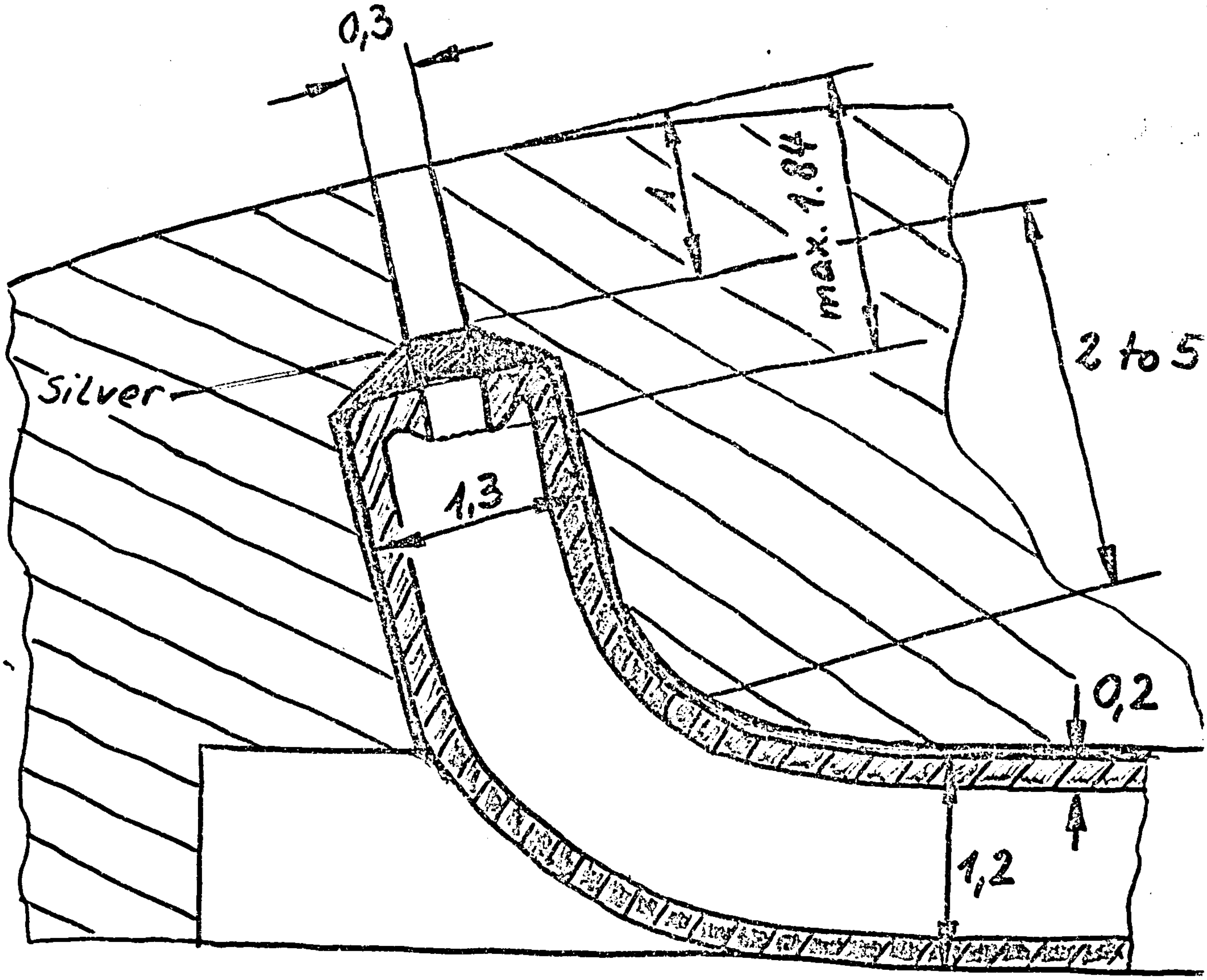


If there is not enough thickness.



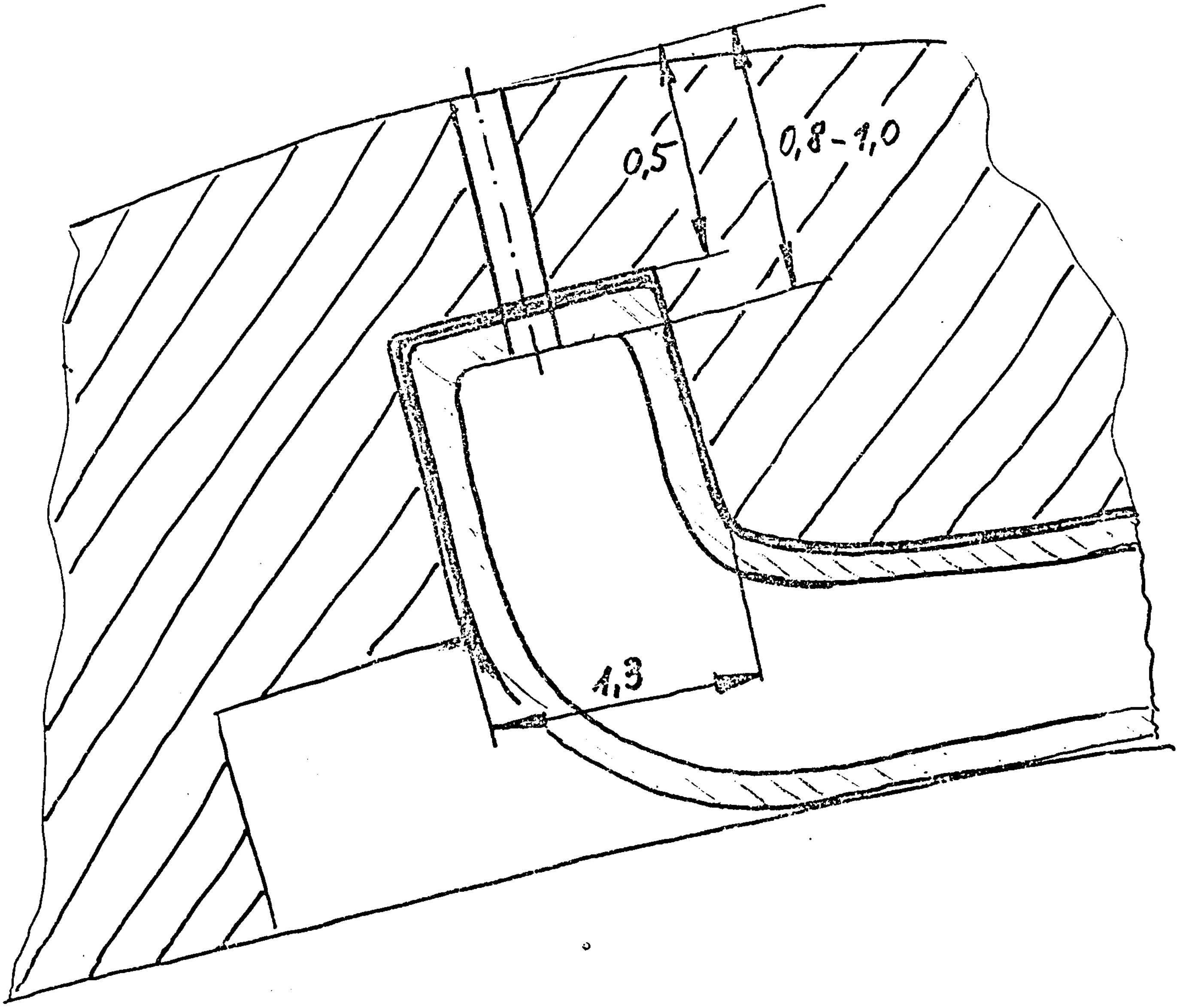


Standard pressure orifice



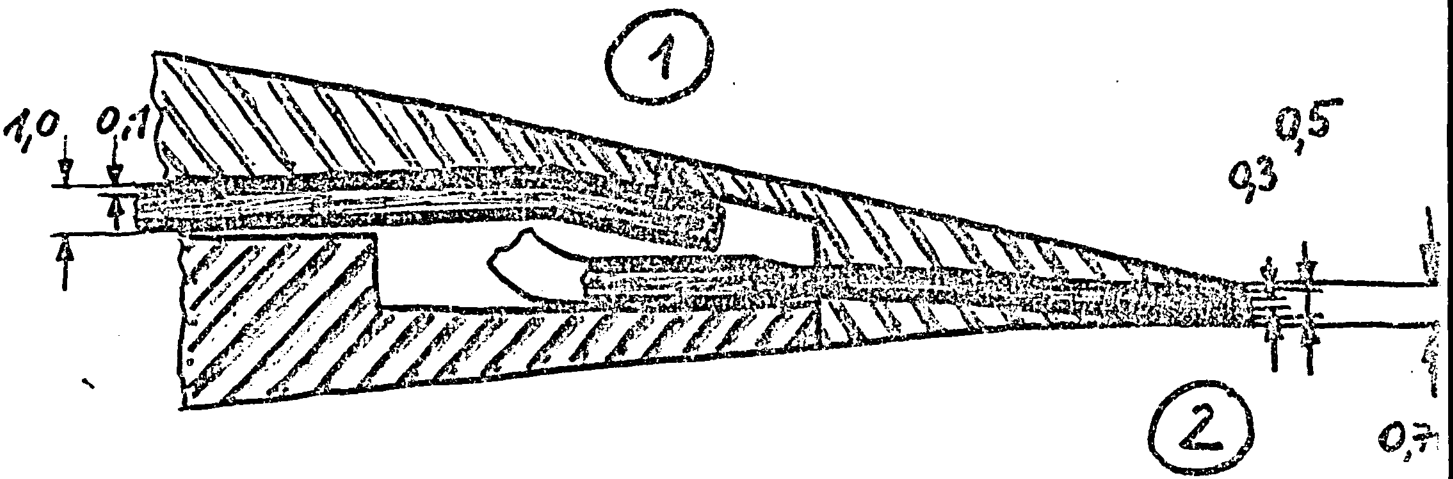
orifices in CAST 10-2, R4

New standard pressure orifice



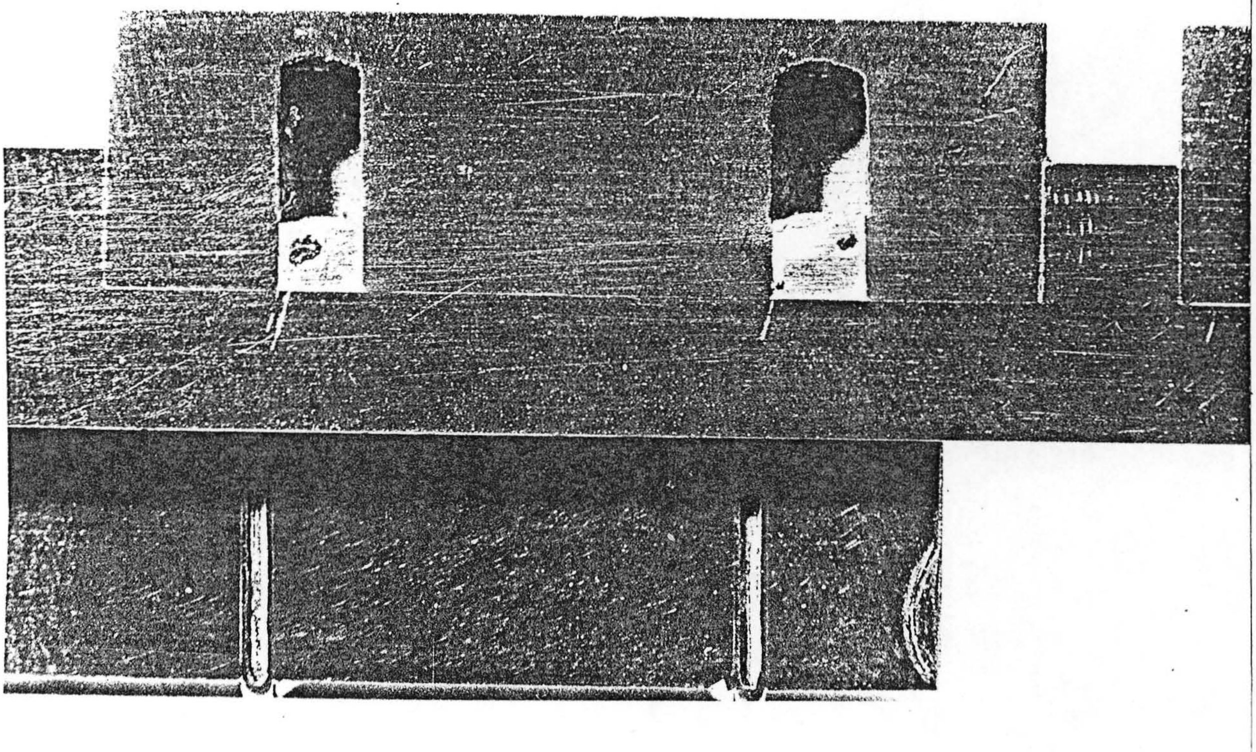
Orifices in a smaller model of CAST 10-2 presently under construction

Special pressure orifice installations



① If model thickness is not sufficient

② If the orifice is located where the tube is thicker than the airfoil.
The tube is reduced in diameter by pulling it through a draw die.



Solder deposits

2.2 MODEL CONSTRUCTION

Work plan:

1. Model upper and lower half pre-milled to rectangular blocks.
2. Approximation of the air-foil contour by stepwise milling.
3. Heat treatment of model halfs at brazing temperature (1120° c), to avoid warpage during later manufacturing processes.
4. Milling and electrical discharging of the channels for the pressure tubes.
5. Drilling of the sockets for the pressure tubes. Positioning and fixing-in-place of the tubes.
6. Silver soldering of the tubes and filling of the solder deposits for the surface brazing in activ and protectiv H, N atmosphere.
7. Check of model dimensions, cleaning of the surfaces, fitting and clamping of the model halfs.
8. Brazing in activ and protectiv gas. Final check for possible model deformation.
9. Cyclic cooling to LN_2-temperatures.
10. Contouring of the model by NC-milling. Hand finishing of the surface. Drilling of the pressure orifices.
11. Final check of the air-foil contour.

Certain stages in the manufacturing process are shown in the following viewgraphs.

HEAT TREATMENT AT 1393 K (1120° C)

1. Both models halfs

   After initial milling work heat treatment in an H-activ gas for stress relief before milling model interior.

   > Cooling during 0.5 hours in the furnace cooling zone to about 300° C.

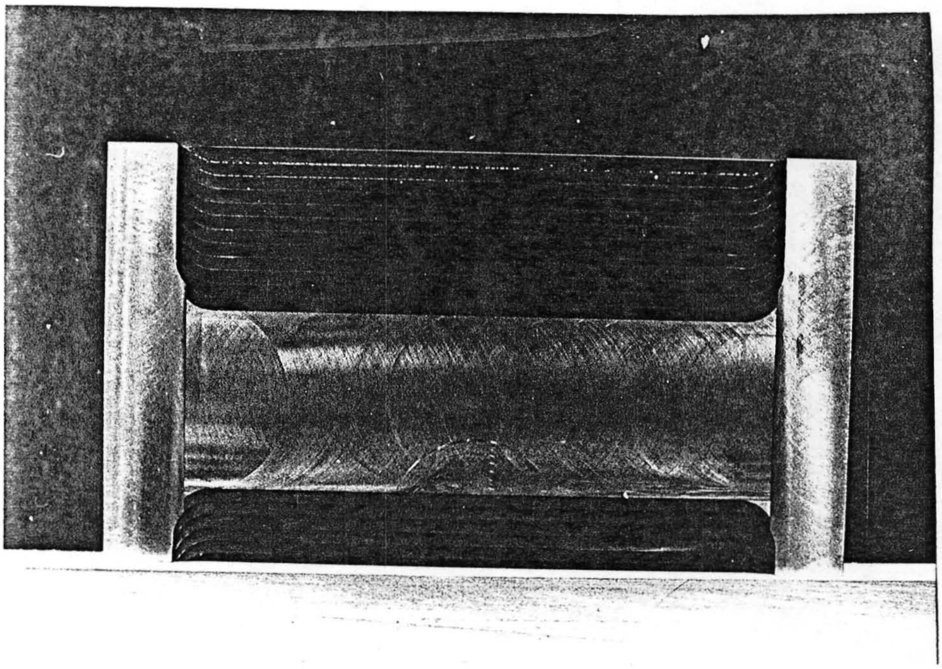
2. Silver soldering of the tubes to the inner sockets.

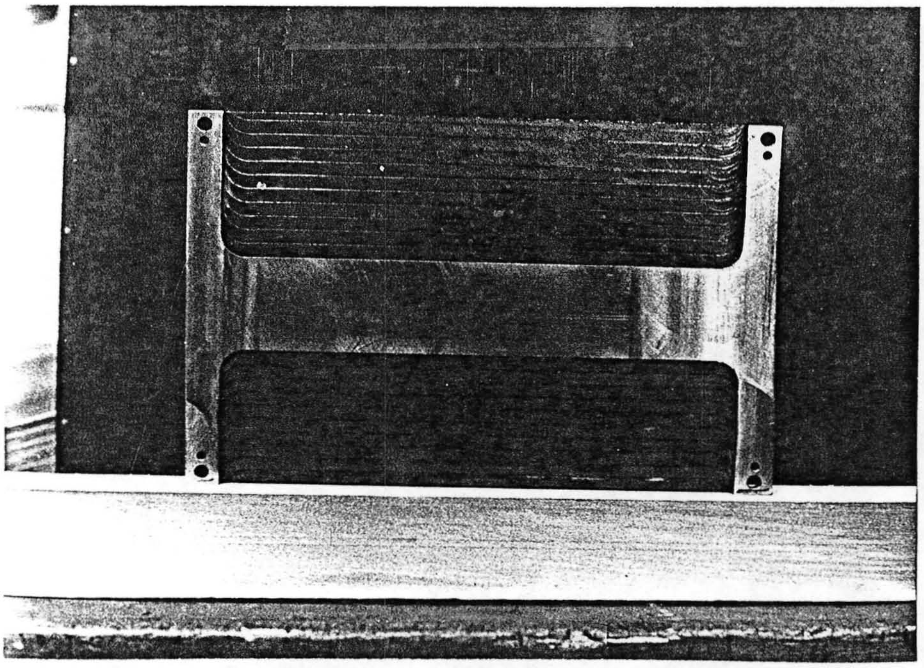
   > Cooling during 0.5 hours in the furnace cooling zone to about 300° C.

3. Brazing of upper and lower model parts.

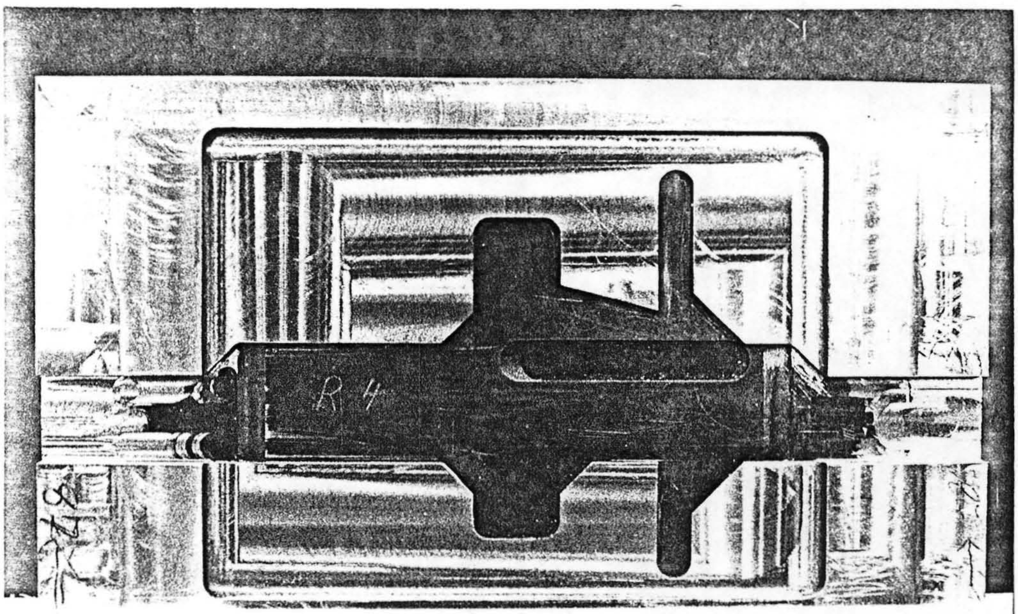
   After the first attempt to braze the model CAST 10-2, an unacceptable barreling of the two parts was observed. In a second attempt the model was weighted down against a solid steel plate during the brazing prozess.
   For the model R4 a specially designed clamping device was used.

Model upper surfaces

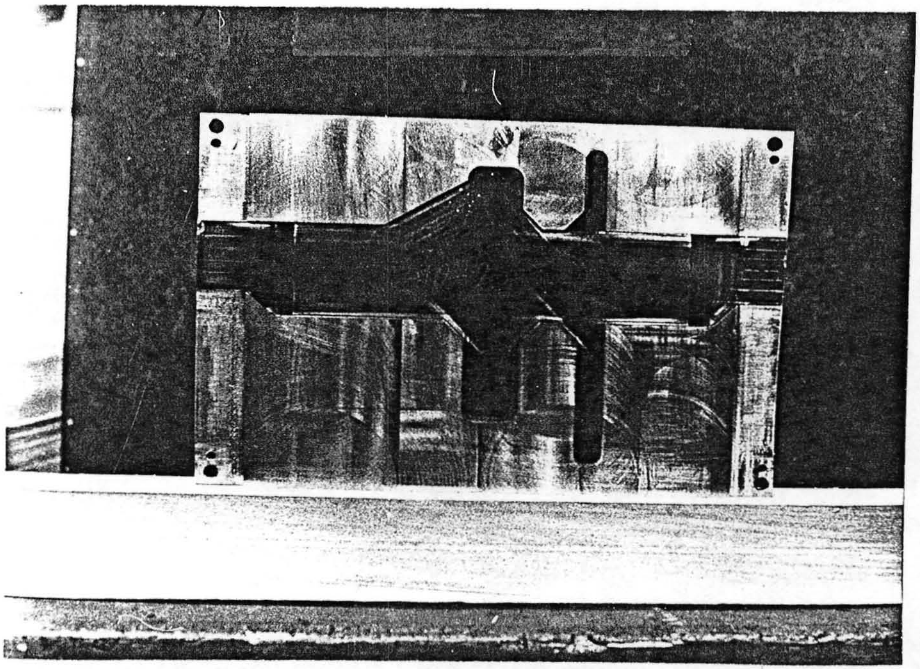




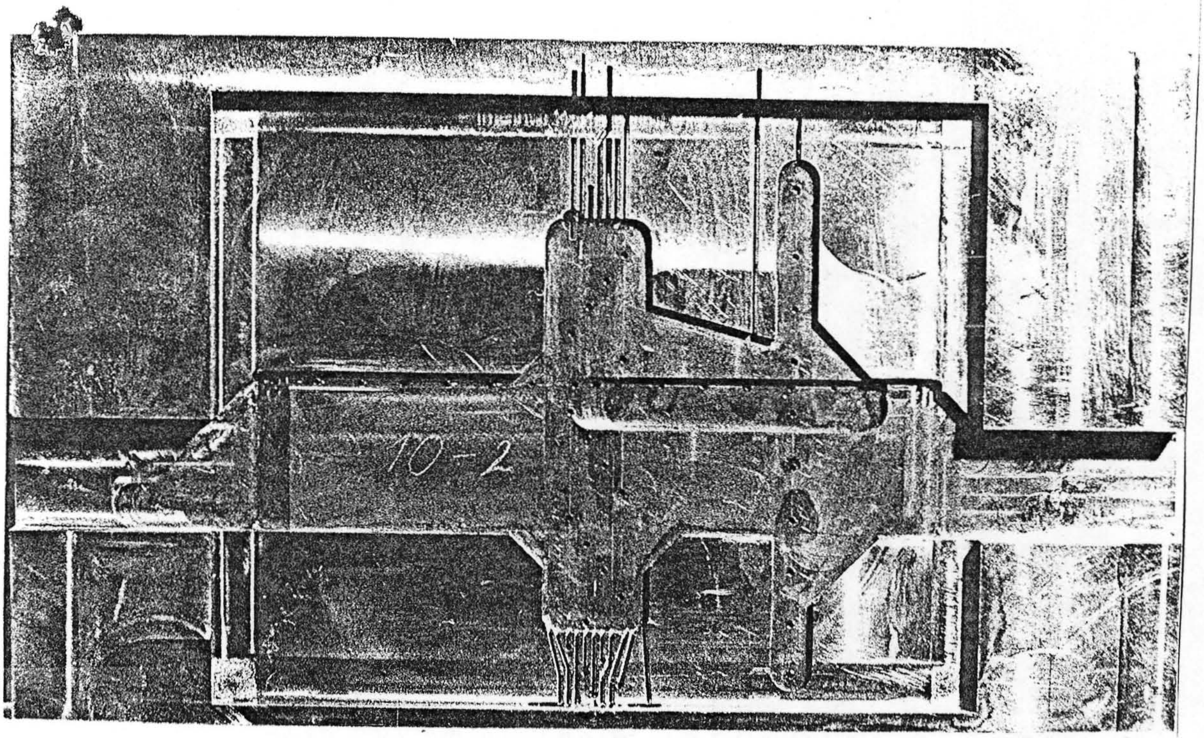
Pre-milled parts before first heat treatment to get the model stress free



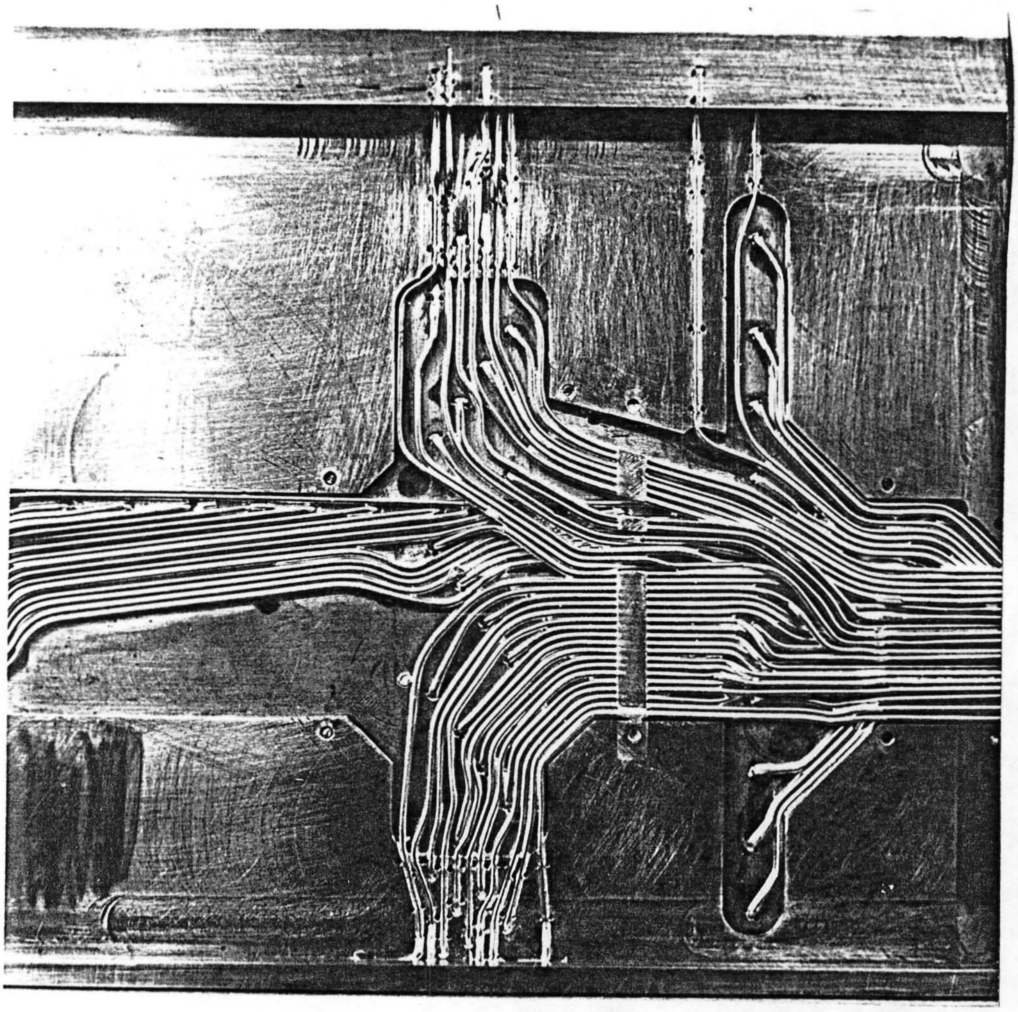
View of the model inside with pocket and tube channels (upper part)



View of the model inside (lower part)

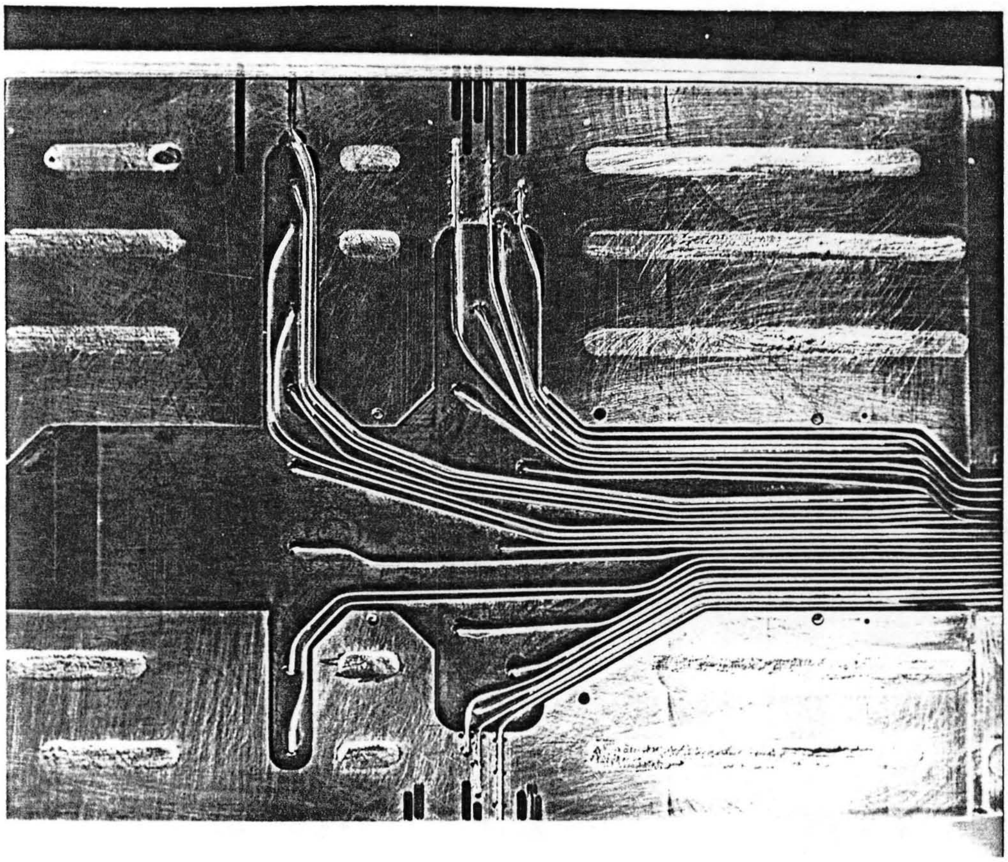


Pressure tube channels and sockets

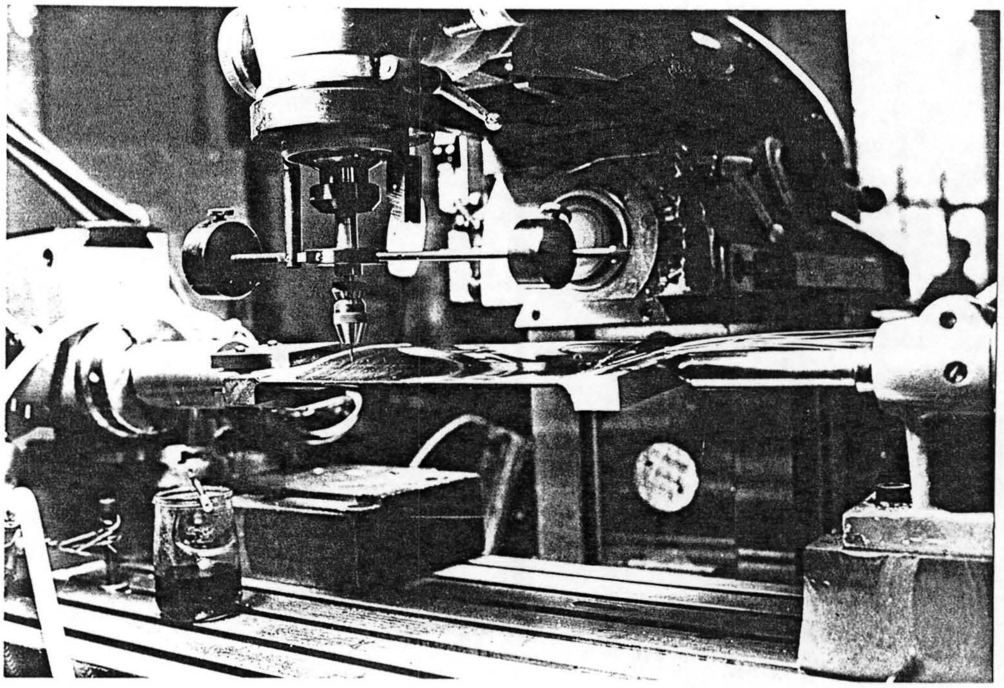


After silver soldering of the tubes

Soldering

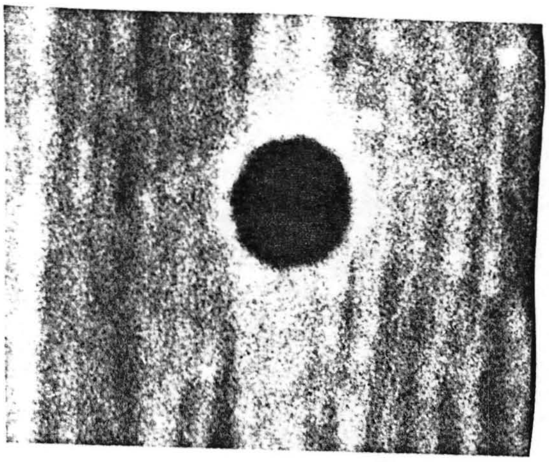


Location of the solder deposits on the pressure side half.
The deposed silver solder can flow in to the plane gap between the model halfs

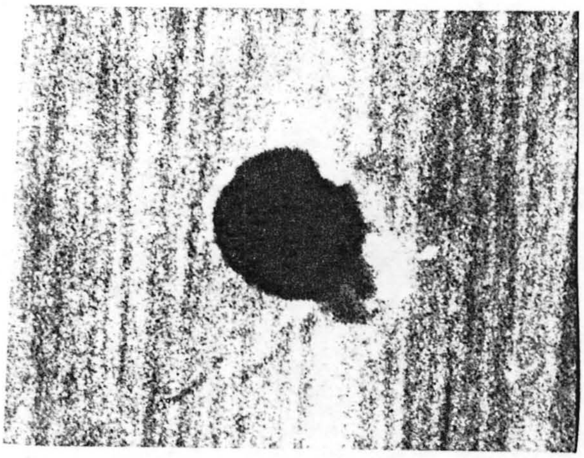


Set up for drilling the pressure orifices with a spezial drilling device

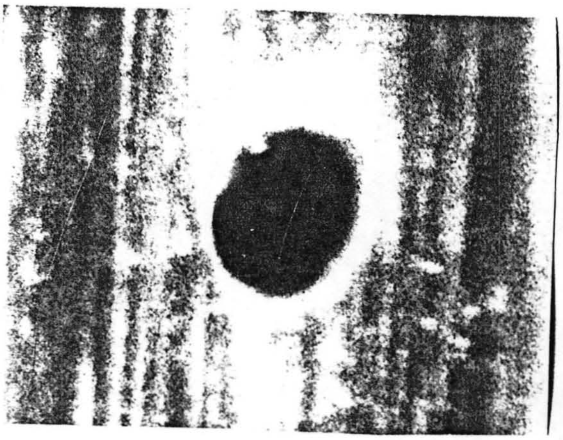
Quality of pressure orifices



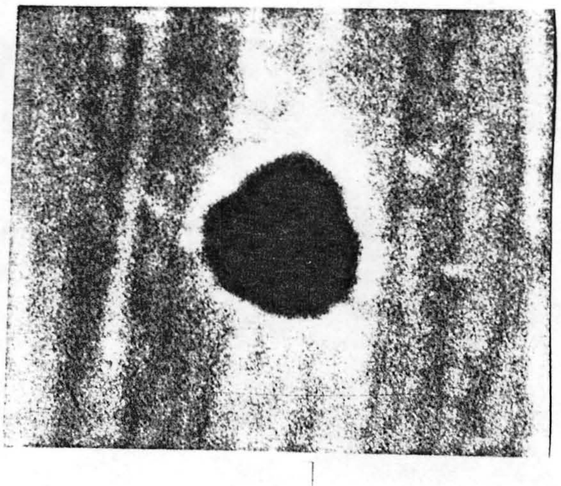
Good orifice
(≈80 %)



Drill not centered

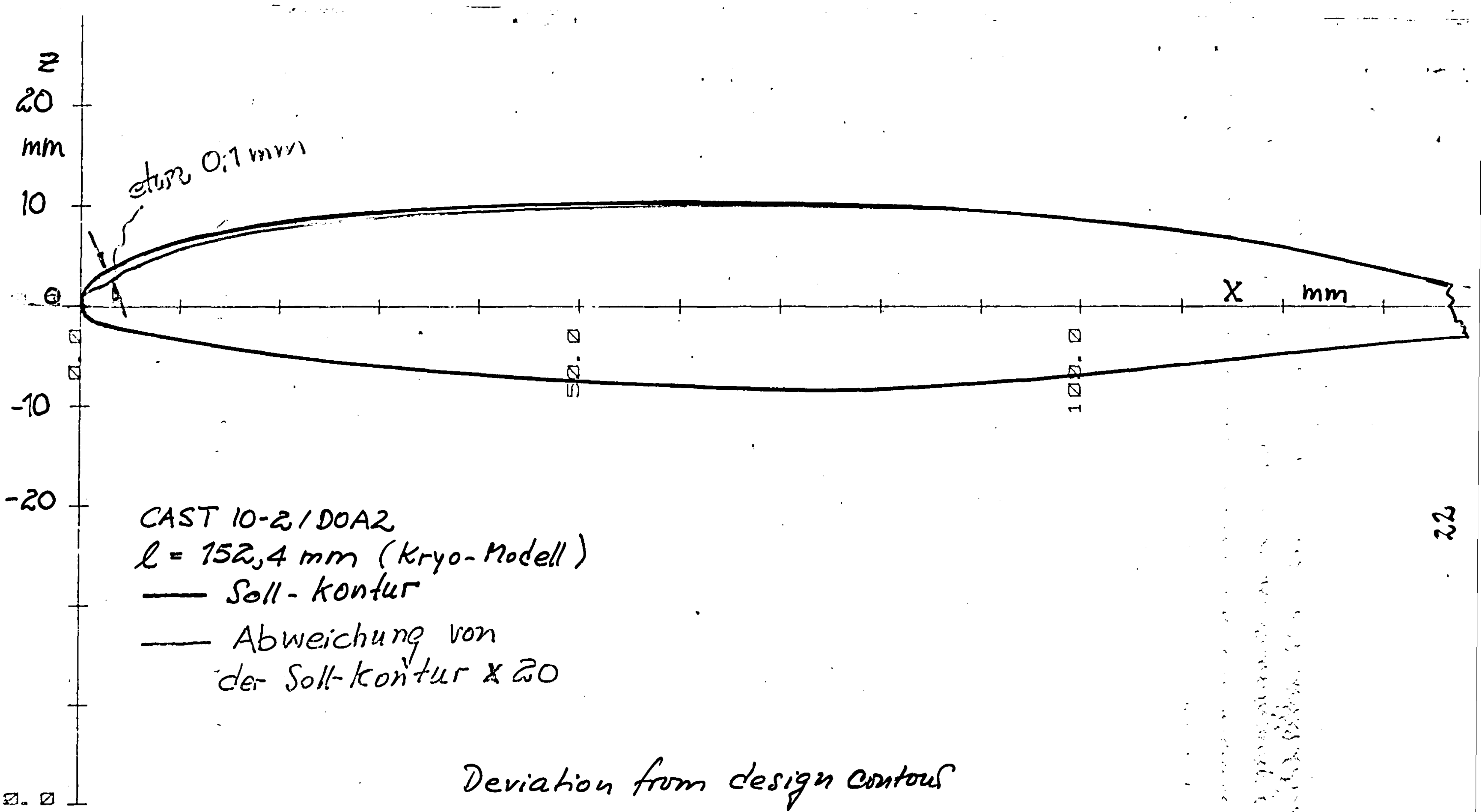


Orifice freed of broken drill tip by electric discharge



Orifice drilled by electric discharge

No effects on the pressure readings were observed.



Deviation from design contour

20.0 2.0 0.0 0.0

100.0 MASSE IN 0.0

CAST10/2 C

PERMANENT MODEL GEOMETRY CHANGES DURING THE CRYO-TESTS

- No spanwise warpage
- No change in plan view dimensions
- No change in surface quality
- No leaking or stopped up tubes
- No gaps between brazed surface
- Model thickness changed by + 0.03 mm (d_{max} = 18.24 mm)

TIME USED FOR MODEL COMPLETION

1. Model construction 5 - 6 month
2. Man-hours for two models

			%
2.1	Design, development	1180	24
2.2	Documentation and NC-programming	290	4
2.3	Construction	3300	67
2.4	Quality checks	250	5
	Total	4920	100

3. SOME AERODYNAMIC RESULTS

In this paper emphasis is placed on model design and construction, however, it is thought of interest to briefly point out some aerodynamic results obtained with the airfoil DAST 10-2/DOA2 in the TCT tests. For details on the airfoil the reader is referred to [1].

In Figure 3.1 the Reynolds number dependence of the aerodynamic parameter in Breguet's range equation is shown for two Mach numbers and fixed and free transition. There exists a strong Reynolds number dependence up to the highest Reynolds number investigated with a clear indication that an extrapolation to higher Re-values on the basis of the existing data is not possible. The high values in the aerodynamic parameter in the lower Reynolds number range are a result of the boundary layer being laminar down to the upper surface shock. The drop in $(C_L/C_D)_{max} \cdot M_\infty$ in that range is due to the transition point moving upstream with increasing Reynolds number.

Figure 3.2 compares results obtained in the 0.3-M TCT with data from the Lockheed Georgia Company Compressible Flow Wind Tunnel (CFWT) and, in the lower Reynolds number range, from the 1 x 1 Meter Transonic Wind Tunnel Göttingen (TKG). Qualitative and qantitative agreement between all three tunnels around $Re = 4X10^6$ and between TCT and CFWT in the Reynolds number range covered by these tunnels is quite good. Especially remarkable is the agreement in the case of free transition between $Re = 4x10^6$ and $Re = 10x10^6$ where the flow development is essentially determined by the movement of the transition point. Note,that the stagnation conditions for the TCT and CFWT are, especially at the higher Reynolds numbers, quite different: They are at $Re = 30x10^6$ for the TCT $T_0 = 115$ K and $p_0 = 4$ bar, for the CFWT $T_0 = 287$ K and $p_0 = 11.9$ bar.

Some deviations between TCT and CFWT results were observed in the development of separation with increasing angle of attack. They are most likely due to side wall effects which are more pronounced in the case of the TCT where the aspect ratio is $b/c = 1.33$ as compared to $b/c = 3$ for the CFWT. In order to better understand side wall effects tests with a smaller model of the airfoil CAST 10-2/DOA2 are scheduled in the TCT.

4. CONCLUDING REMARKS

As part of a NASA/DFVLR cooperative program two transonic airfoils were tested in the NASA Langley 0.3-M TCT. Model design and construction was carried out by DFVLR. The models designed and constructed as described in the preceding sections performed extremely well under cryogenic conditions. Essentially no permanent changes in surface quality and geometric dimensions occured during the tests. The aerodynamic results from the TCT tests which demonstrate the large sensitivity of the airfoil CAST 10-2/DOA2 to Reynolds number changes compared well with results from other facilities at ambient temperatures.

5. REFERENCES

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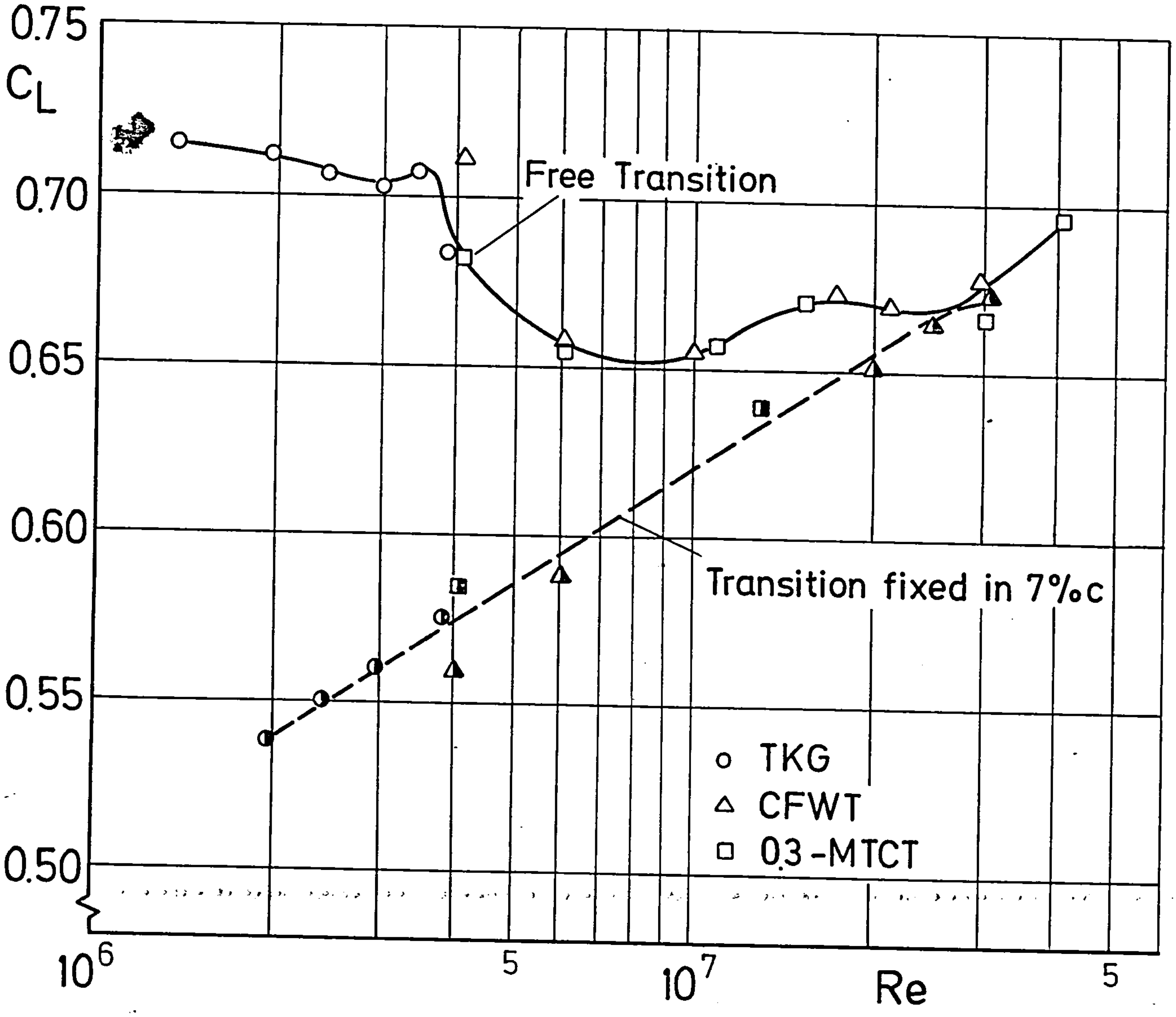

Figure 3.2: Reynolds number dependence of lift as determined in various wind tunnels. $M_\infty = 0.765$ $\alpha = 2°$ Airfoil CAST 10-2/DOA2