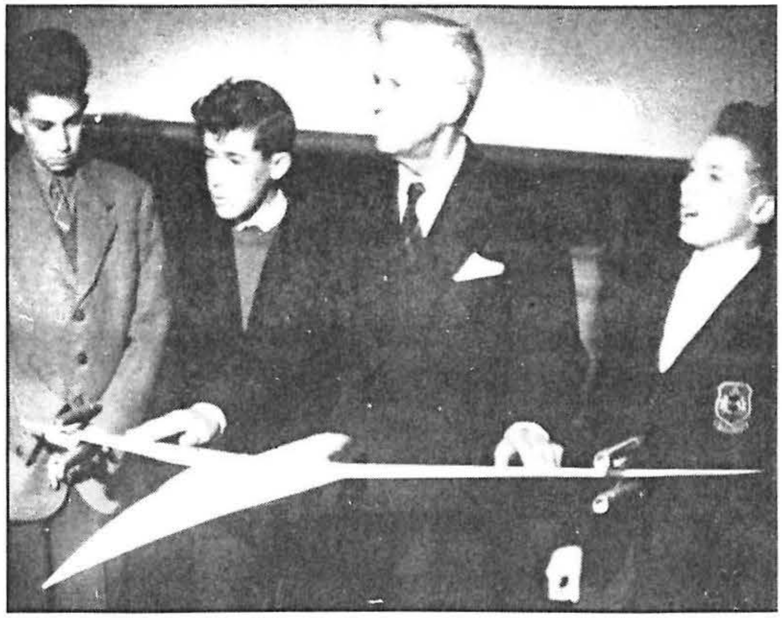
The Wallis Supersonic Long-Range Formula



Above, Dr. Wallis is shown explaining the Swallow, with wings in subsonic position, to some of his audience; below, supersonic configuration.

By JAMES HAY STEVENS. AFRAeS

FIRST INFORMATION about the Vickers-Armstrongs "Swallow" family of supersonic airplane projects was given at an Institution of Civil Engineers lecture (to children!) by Dr. Barnes Nevil Wallis, entitled "High Speed Communications Link the British Commonwealth". The outstanding feature was that the best route from the British Isles to Australia and New Zealand is by the North Pole — for ships as well as aircraft.

The explanation of the former lies in his belief in his experiments with laminar-flow water bodies suitable for freighter submarines 30 ft. in diameter and travelling at 30 kts. This hull form is an elongated ovoid (travelling slim end first) in which laminar flow is achieved by designing the form to give a smooth pressure gradient. Dr. Wallis advocated a similar route to the Pacific for his supersonic airliner, which means a range of 10,000 n.m.! Having made this startling proposition, Dr. Wallis with films and slides outlined the principles and a little of the development of his supersonic "polymorph", i.e., variable-geometry airplane.

First Steps: Development started during the War, when a laminar-flow body with variable-sweep wings and no tail, other than a swept fin, was designed. This, called the "Wild Goose" was successfully flown as a 30 ft. span radio-controlled model launched at 100 mph from a truck on a 400 yard track. A film showed that it was under satis-

factory control, about three axes, simply by co-ordinated, or differential movement of the wings fore-and-aft in one plane to modify the forces of equilibrium. A film of the "Swallow" model, also about 30 ft. span, was shown. This model had a wedge-delta fuselage and its wings were fixed in the forward, high-aspect ratio, position. It took off under its own power, two rockets in the tail, and was controlled by elevons, powerplant nacelle side area being represented by endplate fins. The film showed a high (delta) take-off incidence, due to the 80° sweep of the forebody, the lift from which is essential for stability at all times. Flight was reasonably steady and the level-flight incidence was normal. The model was lost in the English Channel on its first flight through a radio-piloting error. Rocket-boosted models of the supersonic configuration have also been successfully fired, but the Ministry of Aviation would not allow films of these to be shown.

After withdrawing finance from the project in May 1957, the British Government is again supporting it in association with America's NASA and funds are now adequate for the continuance of basic research. Additionally, the Ministry of Aviation has placed a design contract with Vickers-Armstrongs (Aircraft) for a naval "Swallow" which would be developed under the direction of Sir George Edwards. This airplane, which could patrol subsonically for many hours with its wings forward and attack supersonically as they swept back, would weigh about 50,000 lb. and might be powered by Bristol Orpheus turbojets.

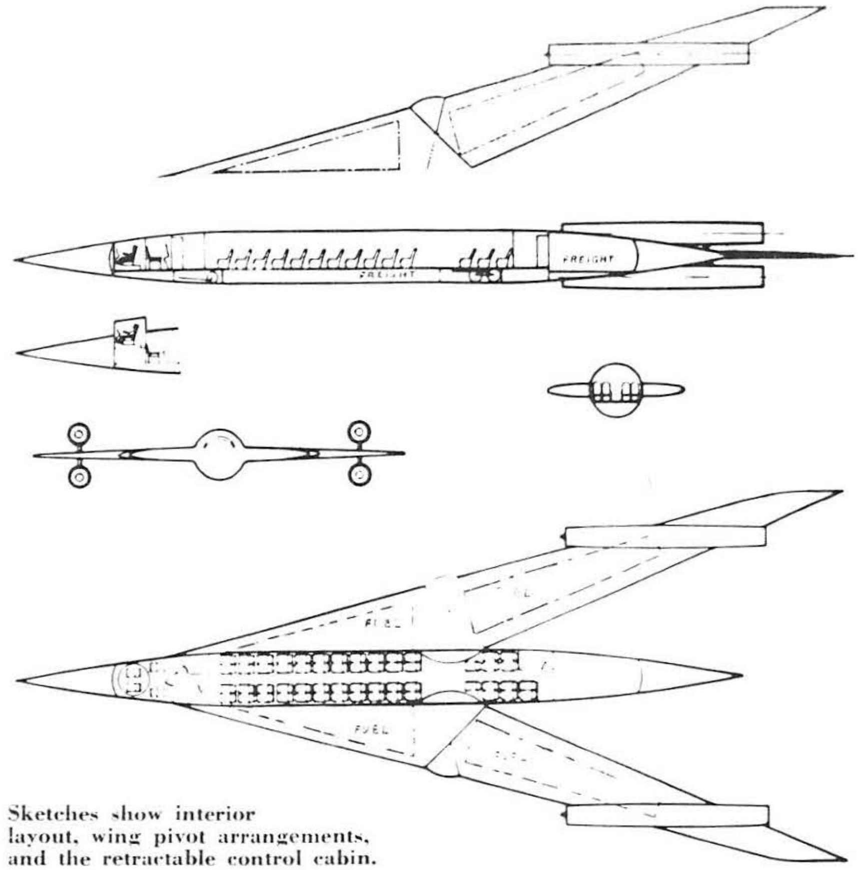
For the "Swallow" (the aerodynamic) philosophy was: "*All* wetted surfaces produce drag, therefore flatten the fuselage and cut out the tail." Furthermore, he cuts out the backside of the delta, which contributes little lift and large separation drag in supersonic flight.

First Impression: The first thing that strikes one is that, in the definitive supersonic form, it is a strictly homogeneous envelope: a sharp delta with all surfaces lying behind the high-pressure air of the Mach cone. The delta body/wing blends smoothly with the high aspect ratio "swallowtails": from the markedly cambered nose of the former to the washed-out tips of the latter. Although the nose itself is sharp, the leading edges are radiused throughout — remarkably so along the sides of the forebody. The basic cross-section of the forebody is a flattened elipse, out of which grow the slender wings and a cylindrical, ogivally tapered, central tail which increases cabin capacity and probably provides a tail-wheel support and stowage. A retractable cockpit is needed to prevent the pilots from being cooked after several hours at Mach 3 and to provide landing and take-off view. Running fore-and-aft along the top of the wing are two large strakes, much at variance with the general smoothness of the whole aircraft. It may be recalled that windtunnel tests on narrow deltas have shown the development of twin separation vortices at high incidence.* Strakes such as those on the model could well be fences to prevent the spread of these vortices at the necessarily high take-off and landing incidence — they would also be in about the right place for undercarriage fairings.

The reason why a "swallowtail" delta had not been tried before was that it would require a twenty foot high undercarriage because of the wingtips. After the earlier Wallis variable-sweep experiments the solution was obvious: simply swing the swallowtails forward some 70° to make them into high-aspect ratio wings for low speed. Figures of 130 ft. span spread (with similar overall length swept) and 40 lb./sq. ft. wing loading were given (in the lecture) for the 100,000 lb. airliner; therefore the wing area, the *entire* aircraft, is 100,000÷40=2,500 sq. ft. and the aspect ratio at low speed would be 6.8 — though there would be considerable gain, one would think, in induced drag from the swallowtails of which the aspect ratio must be about 15. A take-off in a few hundred yards at 100 mph was mentioned, which implies high acceleration as well — assisted, one would imagine, since take-off thrust/weight ratio is not all that high.

Greatest Problem: With variable sweepback, the greatest problem is to maintain correct c.g./c.p. relationship as the entire lift and stability pattern changes with the movement of the wings. Drawings show that the wings contain fuel from root to nacelle — the sides of the delta also have long tanks in them. The c.p. moves aft with the wings and, as there is no tail or fore plane for trim, longitudinal stability will have to be supplied by appropriate adjustment of longitudinal dihedral between the wing/body and the "swallowtails". Apparently, the engines near the wingtips are the major factor in bringing the c.g. aft in sympathy.

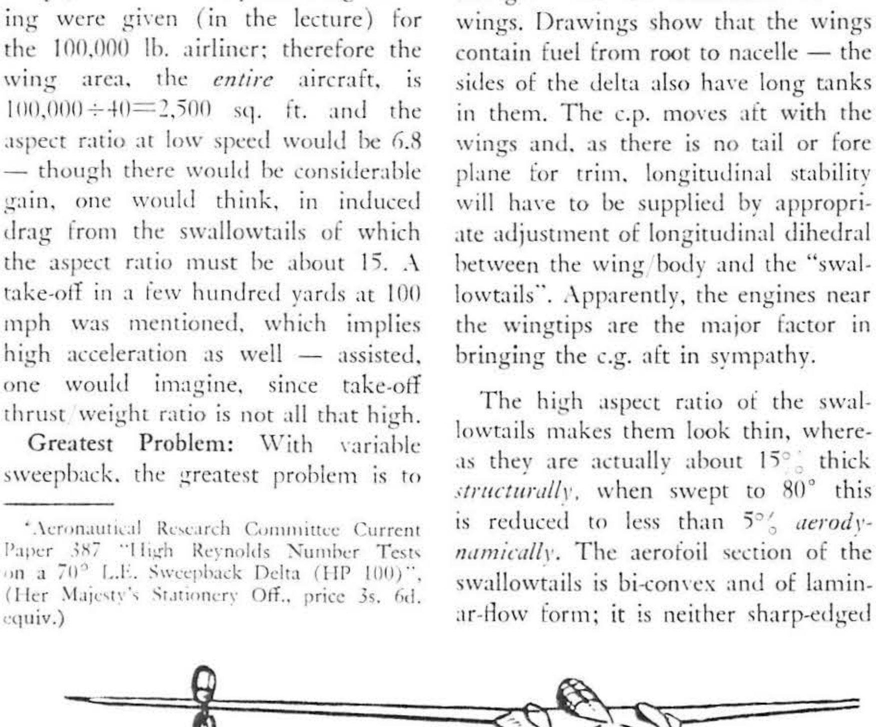
*Aeronautical Research Committee Current Paper 387 "High Reynolds Number Tests on a 70° L.E. Sweepback Delta (HP 100)", (Her Majesty's Stationery Off., price 3s. 6d. equiv.)



Sketches show interior layout, wing pivot arrangements, and the retractable control cabin.

The high aspect ratio of the swallowtails makes them look thin, whereas they are actually about 15% thick *structurally*, when swept to 80° this is reduced to less than 5% *aerodynamically*. The aerofoil section of the swallowtails is bi-convex and of laminar-flow form; it is neither sharp-edged nor symmetrical and the incidence washes out markedly. The tips are cut away to be in the line of flight when fully swept. One would expect a reduction of incidence, relative to the body, as the wings move forward.

Because variable sweepback necessitates the engine nacelles swivelling through 70°, they might as well be universally mounted and power operated to act as elevators, ailerons and rudders. They also provide some vertical fin area — the acute delta would be highly stable at supersonic speed, while slight toe-in of the widely-spaced thrust lines could compensate for the shortage of fin area at low speed. Once the engines are universally mounted, there are many possibilities, of which coupling to autostabilizers for trim and offsetting for asymmetric flight (automatically upon power failure at take-off) are immediately obvious. It is important to realise that the control use of the nacelles is *aerodynamic*, any thrust-deflection effect is purely coincidental — except possibly in the dead engine cases. The mechanics of the universal mounting, which must be held rigid against feedback or flutter, and the actuating mechanism must have required as much ingenuity as the wing joint. The need to move the nacelles in pitch



As wings move, engine nacelles maintain position relative to datum line.

necessitates triangulated mounting pylons with their apices adjacent to the surface. The nacelles project well ahead of their pylons so that the engines mass balance the wings, as well as their own mountings, against flutter. In side elevation the paired nacelles are reminiscent of Busemann's supersonic biplane, so that there may well be favourable shockwave interaction.

Wing Joint: Two hints have been given by Dr. Wallis about the wing joint, the key to the project. Dr. Wallis has likened it to the human hip joint and in his lecture he said it is "something like that used for training a gun". This suggests that, instead of having a hinge at the very root of the wing, a fulcrum and lever have been evolved by Dr. Wallis' genius. The "hip joint" could be the fulcrum or trunnion, with an inboard extension of the wing spar and an arcuate rack-and-pinion representing the "gun mechanism". Such a device would have the immense advantage of giving relief in bending, since the traditional bogey of the encastré wingroot has been sidestepped — it would be analogous to the ball joint at the base of a tall radio mast. To be effective, bearing loads have to be reduced to a low value (as in the pin joints of idealized structures) another key secret.

Dr. Wallis is known to have worked out some most unusual solution to the heat problem of flying for many hours at Mach 3. In this connection he mentioned that he considered the limit for sustained atmospheric flight would be M4.57, since "the equilibrium temperature of 300°C. was too high even for steel", and the practical speed would be M2.5-3.0, equilibrium temperature about 150°C.

Flight control of the "Swallow" would be by conventional control column and rudder pedals. Nothing has been divulged about the wing sweep control, but since it is a function of acceleration and speed it is psychologically linked with the throttle, so far as the pilot is concerned, although it would obviously be related to some form of automatic control through a Machmeter. So long as increase of drag, when rapidly applied, is not accompanied by unpleasant compressibility effects, the reverse action is potentially the most powerful speed brake yet devised. Put another way, the speed of the "Swallow" will always lie below its M_{crit}, which is related to the Mach angle of the bow shock, behind which the wings lie at all speeds. Acceleration must, therefore, be a co-ordinated effect of reduced wing wave drag (and frontal area) plus, perhaps, increase of thrust from the rising ram recovery. Once accelerated, power would be reduced to the remarkably low values needed to maintain the design speed.

Calculations: Some simple sums based on figures given at the lecture add interest to the project.

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CF-104: VARIATIONS ON A THEME

A round-up of the points of difference and features of the CF-104, as compared to the Starfighter variant on which it is based, was recently released by Canadair Ltd.

The CF-104 strike-reconnaisance fighter being built for the RCAF is the Canadian version of the F-104G, which has been adopted also by the air forces of West Germany, Belgium and Holland. The Canadair-built CF-104 is intended as a replacement for the Sabre 6's presently in service with Canada's eight day fighter squadrons in Europe.

Like earlier marks of the F-104, the Canadian version will be capable of Mach 2 flight. Major difference is in the beefed up structure to withstand the higher wing and airframe loadings that can be expected in its low-flying role. A number of new forgings are incorporated in the fuselage main frames, wing fittings and spars, fuselage longerons and joints, fuselage tail frames, tail unit spars and ribs.

The vertical tail surfaces have been enlarged by 25% and a fully-powered rudder has been added to give more precise control during attacks on ground targets. The horizontal stabilizer mechanism has been modified to give increased hinge-movement.

Maneuvering flaps have been added to provide an increase in the available load factor. This will reduce the turn radius by one third at an altitude of 5000 feet, a significant advantage for ground attack operations.

The drag chute diameter has been increased from 16 feet to 18 feet to reduce landing roll. To meet possible icing conditions during low high-speed flight, electrical de-icing elements are fitted to the air intakes.

Max range for specific bombing missions is allowed for by the provision for installing aluminum fuel tanks in the ammo, gun and shell case compartments of the fuselage. This installation is interchangeable with the gun and increases the internal fuel capacity by 120 gallons.

As with other late models of the Starfighter, the CF-104 has a conventional upward ejection seat instead of the downward system used in early models.

Other interesting features of the CF-104 include: anti-skid wheel brakes; provision for the pylon-mounting of Sidewinder missiles under the fuselage; a large-calibre rocket and other external armament stores under the wings along with extra fuel tanks.

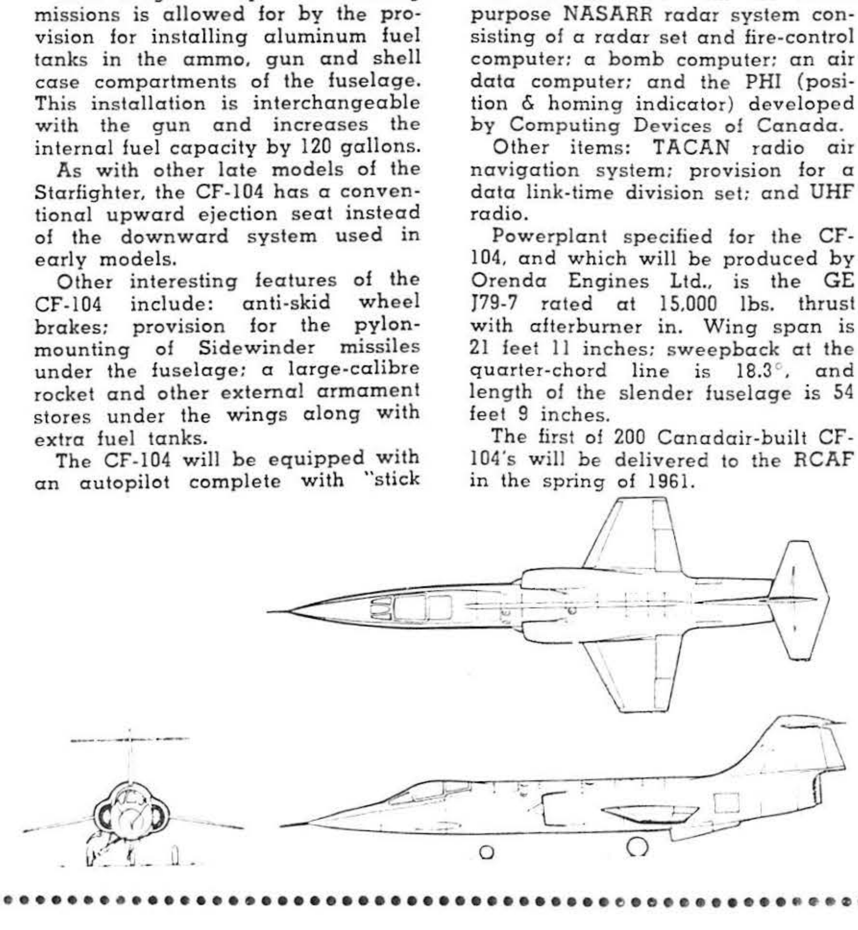
The CF-104 will be equipped with an autopilot complete with "stick steering". This will include modes for preselecting and holding altitude, speed, heading and a constant rate of turn.

It will be fitted with the multi-purpose NASARR radar system consisting of a radar set and fire-control computer; a bomb computer; an air data computer; and the PHI (position & homing indicator) developed by Computing Devices of Canada.

Other items: TACAN radio air navigation system; provision for a data link-time division set; and UHF radio.

Powerplant specified for the CF-104, and which will be produced by Orenda Engines Ltd., is the GE J79-7 rated at 15,000 lbs. thrust with afterburner in. Wing span is 21 feet 11 inches; sweepback at the quarter-chord line is 18.3°, and length of the slender fuselage is 54 feet 9 inches.

The first of 200 Canadair-built CF-104's will be delivered to the RCAF in the spring of 1961.



RADIO THEORY

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that 121.9 megacycles has a wave-length of 2.4 meters and 500 kilocycles has a wave length of 600 meters. Commercial broadcasting stations in Canada have wave lengths that range from 540 to 200 meters.

The formula also indicates a very significant point. That is that the higher the frequency, the shorter the wave length. Consequently, since antennas must be matched to the frequencies being transmitted and received, the higher the frequency, the shorter the antenna required. Actual antenna length is a compromise involving a number of factors such as space available, cost of construction, frequencies to be used and the power being used. Exact antenna matching is usually automatically accomplished by the addition or subtraction of inductance (coils) or capacitance (condensors). Adding inductance in series to the antenna, electrically lengthens the antenna and adding capacitance in series electrically shortens the antenna.

In the next article, the frequency spectrum, frequency application, skip distance, skip zone and propogation will be discussed.

SUPERSONIC AIRLINER

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The 50,000 lb. gross weight naval project may have four Bristol Siddeley Orpheus, say 5000 lb. thrust each at sea level, a quarter of that at 60,000 ft. or so — the likely height for supersonic cruising. The 10,000 n.m. airliner might be supposed to have a similar thrust/weight ratio. At 100,000 lb., this would mean a total cruising thrust of 10,000 lb. Thus, cruising L/D=100,-000÷10,000=10.

Dr. Wallis said his BOAC "Swallow" airliner project would carry 50 or 60 passengers, say 15,000 lb. including baggage and crew: 100,000—15,000=85,000 lb.

Assuming 30% of the gross for structure: 100,000—30,000=70,000.

This leaves 55,000 lb., or about 7000 IG, for fuel and a reasonable assumption for the cruising sfc of a low pressure ratio supersonic engine is 1.0.

Thus, 55,000 lb. of fuel would last 5.5 hours, or almost 11,000 statute miles at Mach 3 (2000 mph) which seems near enough for an armchair "guesstimate", but rather tight on allowances for London-Melbourne.

However, let us suppose that this graceful aerodyne has an L/D of 12, the optimum value for supersonic range, and one gets this remarkable picture:

100,000÷12=8350 lb. thrust for cruising,
and 55,000÷8350=6.6 hours,
or 13,200 statute miles, i.e. 10,000 n.m. with 1,500 n.m. reserve, which fits logically into the route pattern.

Finally, it must be clearly understood that there is no Vickers Swallow, as such, there is a whole range of "paper airplanes" designed on a similar principle to meet different specifications. The officially-released airliner must be an early study before the full implications of the airflow and lift pattern of wedge-delta wings was understood. Today, aerodynamicists realize that the body and wing *must* be blended like the demonstration model. One would also guess that because of the need for blending there is a minimum practical size for this configuration — even with a prone pilot — since the cockpit must be extended and retracted.

NAE WIND TUNNEL

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system and fine mesh wire smoothing screens installed in the settling chamber of the tunnel. The steady air flow leaves the settling chamber by a convergent fixed contraction and is further accelerated in passing through the supersonic nozzle. The shape of the air flow passage of the supersonic nozzle is provided by two 45 ft. long, 5 ft. wide, 0.86 in. thick, flexible steel plates, acting between parallel side-walls. Each of these plates is positioned against accurately set mechanical stops by 22 hydraulic jacks. Various stop settings, giving a range of convergent-divergent nozzle shapes and test Mach number, are available.

Transonic Testing: For tests in the transonic range a special test section is inserted into the wind tunnel circuit between the supersonic nozzle and model support section. This transonic test section, which is 16½ ft. long, has perforated flow surfaces surrounded by a 12 ft. diameter plenum chamber. Models are supported from the base by a mounting sting which is attached to a vertical strut. Housed within the model support system are hydraulic servos which provide model attitude control, in pitch and roll, during a tunnel run. The air forces acting on the model during a blowdown are measured electrically by a strain gauge balance mounted within the body of the model and air pressures are converted to analogue voltages by pressure transducers. The air flow through the test section is slowed down in the variable and fixed diffusers and finally discharged to atmosphere through an exhaust silencer designed to reduce the outlet noise to an acceptable level.

The aerodynamic measurements made during a run, which are electrical voltages proportional to model loads and pressures, are measured by self-balancing strip chart potentiometers fitted with digitizers and recorded on IBM punched cards. Subsequent processing in computing equipment gives the reduced results in tabular and plotted form.

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