

April 9, 1963

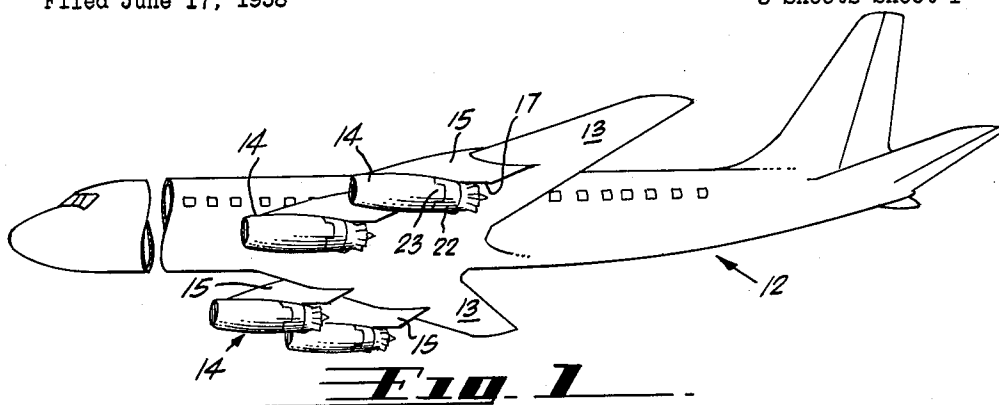
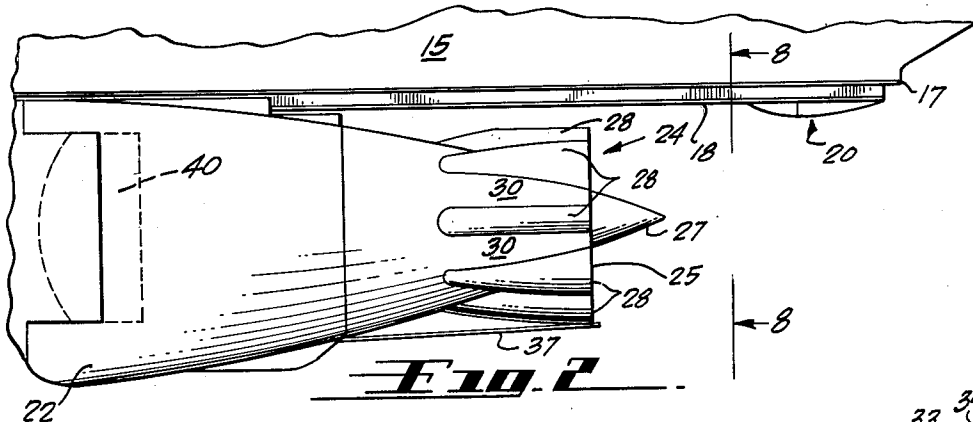
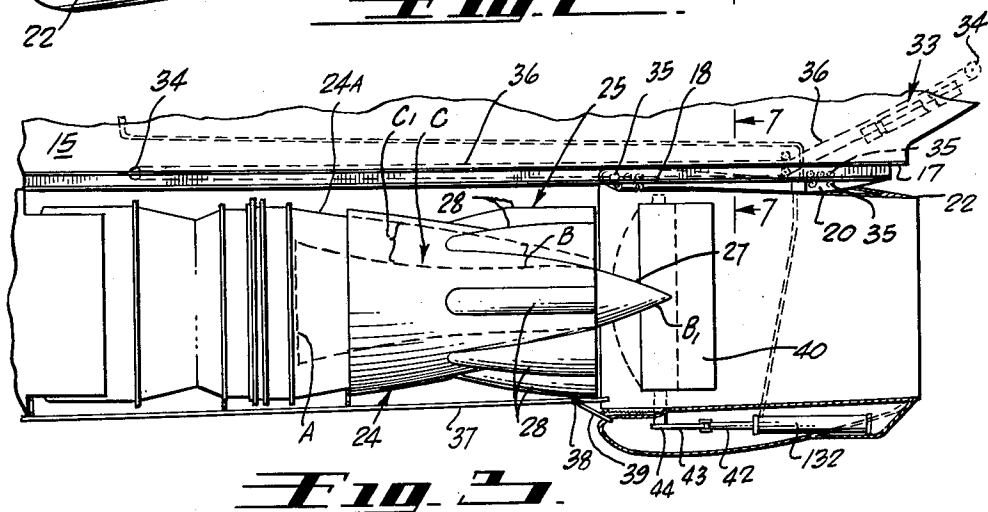
S. KLEINHANS ET AL

3,084,507

JET ENGINE SOUND SUPPRESSOR AND REVERSER

Filed June 17, 1958

3 Sheets-Sheet 1



INVENTORS
SCHUYLER KLEINHANS
CARLA A. WEISE

By *Edwin Coates*
ATTORNEY

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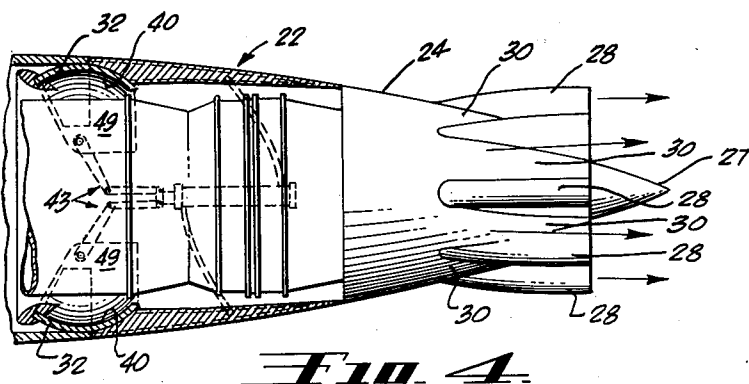
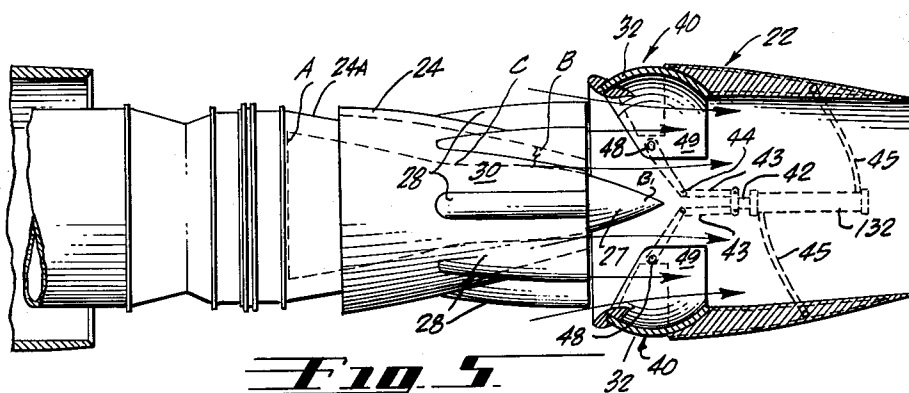
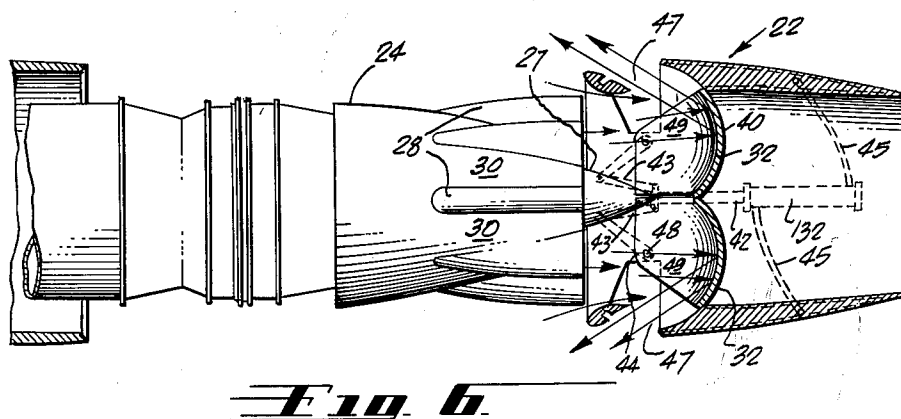
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3 Sheets-Sheet 2



INVENTORS
SCHUYLER KLEINHANS
CARL A. WEISE

Edwin Coates
ATTORNEY.

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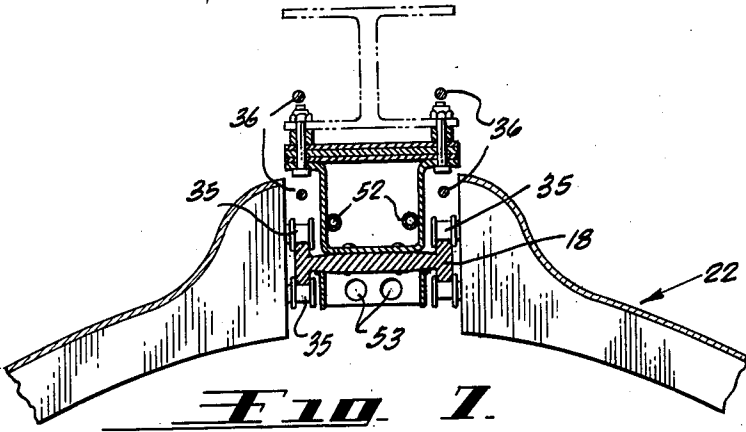
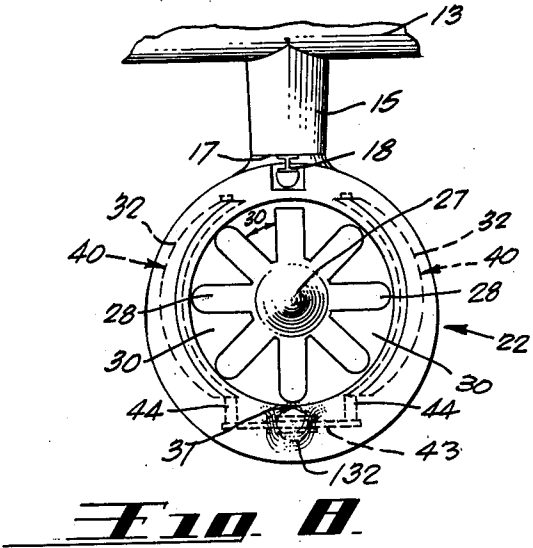
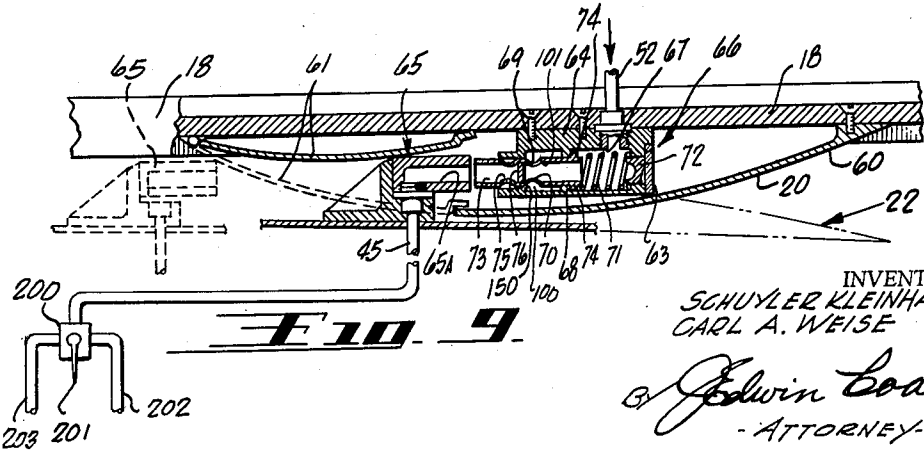
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3 Sheets-Sheet 3



INVENTORS
SCHUYLER KLEINHANS
CARL A. WEISE

Edwin Coates
- ATTORNEY -

1

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JET ENGINE SOUND SUPPRESSOR AND REVERSER

Schuyler Kleinhans, Santa Monica, and Carl A. Weise,
Pacific Palisades, Calif., assignors to Douglas Aircraft
Company, Inc., Santa Monica, Calif.
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4 Claims. (Cl. 60—35.54)

This invention relates to jet aircraft engines and the noise problem they create, particularly during ground "run-up" of the engines and during take-off, as well as during flight.

The sound emitted by conventional jet engines is caused chiefly by turbulence in the "free stream" boundary between the exhaust gases and the ambient air and, in fact, occurring in the entire mixing region. The amplitude and frequency of this noise vary with the velocity difference between that of the jet and that of the ambient air. The "sound power" varies as the eighth power of the velocity difference, this fact roughly indicating the noise potentialities inherent in a jet exhaust. The power is radiated unevenly from the exhaust orifice in various spatial directions and throughout the entire sound-frequency spectrum. The maximum intensity, however, is found behind the airplane's wings, off at about 30° from the jet axis. The effect on persons on the ground aft of the jets is therefore the chief consideration, either during run-up, takeoff, or in flight. The frequencies of greatest noise-intensity are directly related to the effective diameter of the jet orifice, generally being of lower frequency with orifices of large or "unbroken" diameter, and the low frequencies produce the most obnoxious amount and kind of noise.

The local intensity of the noise is of especial importance and is generally given as "overall sound level," comprising all audible frequencies, and this level is expressed in decibels. The obnoxiousness varies with the decibels. For example, conversational speech has a sound level of 60 db, which is usually unobjectionable, but noise above 120 db causes instant and severe damage to the ear drum. The noise level is measured herein, for more complete analysis, in individual octaves or in any desired band width of frequencies. The peak overall sound level of a conventional jet engine is of the order of 130 db at a distance of 150 feet rearwardly of the wings or 112 db at a distance of the order of about 1,000 feet therefrom.

It has been mentioned that the "sound power" is highly dependent on jet velocity. The conventional sound suppressor endeavors to transform a narrow, high velocity, stream into a "final" wide, low velocity stream as quickly as possible and as close to the trailing edge of the main exhaust nozzle as is feasible. By the momentum-conservation law, thrust (=mass flow $\times$ velocity) is a constant in this connection. Any decrease in velocity can be achieved therefore, only by an increase in mass flow. Noise suppressors therefore aim to expedite the mixing of exhaust gases with ambient air, also called the secondary air as contra-distinguished from the ram air, or engine-intake-air, and aim to effect the mixing as near to the instant of exit of the exhaust as is feasible. The mixing process is one of "diffusion of momentum." Convection of the gaseous bodies is aided by the turbulence in them and "conduction of momentum" in them is herein aided, among other things, by an enlarged but integral or continuous perimeter for a given nozzle average, or "circumscribing" diameter. This enlarged, or fimbriated, perimeter-created pattern into which the jet is broken is herein stiffened and kept from collapsing too quickly by auxiliary means, called an inductor or inducer, or ejector, configured for positively inducing complete

2

mixture of exhaust with ambient air, among other things effected thereby.

The invention thus contemplates, among other things, the steps of, and means for, dividing the initial jet into a pattern comprising a plurality of diametrically smaller and substantially discrete but centrally interconnected sub-streams as soon as feasible with reference to the emission of the exhaust from the secondary combustion chamber of the engine itself. As a consequence, a greater mass of "secondary" air, or ambient, nonram air, can be hereby constrained to mix with the exhaust stream in a substantively shorter distance longitudinally of the engine and in a substantively shorter time than heretofore deemed feasible.

Further, the "principal frequency" of the noise of such altered jet is hereby elevated by, among other provisions, the much smaller effective diameter of these separated streams established herein.

The rationale of this action is that these elevated, high frequency acoustic pressure waves can then be made to be "absorbed" by the ambient atmosphere so quickly and in such a short distance that these "waves" decay or attenuate surprisingly more quickly than heretofore, while the shorter distance in which they are constrained to mix minimizes their opportunities for radiating spatially.

The general usefulness of an inducer, also sometimes referred to as "inductor" or "ejector," as a thrust augmenting device is fairly well known. In order to be effective as a noise suppressor, however, an inducer must have a length pre-calibrated with respect to the foregoing factors, plus the considerations of the weight and drag concomitant. With standard jet nozzles, the conventional inducer length must equal about ten nozzle diameters. However, this invention is predicated, among other things, on the fact that the requirements of inducer length are also dependent on the local primary exhaust stream diameter, rather than on the total diameter of the nozzle. Thus the very factors which speed mixing also turn out herein to also render the optimum length and diameter of an inducer for present purposes about equal to the minimum theoretically conceivable length and diameter thereof. The length factor of about ten diameters still applies but, since the effective local stream diameter is greatly reduced, the necessary inducer length is reduced proportionately.

The net merit of any sort of jet exhaust sound suppression device of course lies in the actual amount of reduction of noise that it effectuates, both for the passengers and for persons on the ground at and surrounding the airport. Each reduction by an amount of 6 db represents a reduction of about 50% in the acoustic pressure and concomitant factors. However, the present invention, by empirical demonstration, reduces this variable in the amount of at least 12 db and in some cases by as much as 15 db. This represents a diminution of the sound pressure by an amount equalling $\frac{1}{4}$ to $\frac{1}{8}$, more, at least, than that which heretofore was deemed feasible to accomplish.

Previous speculation has produced two general, but substantially ineffective, types of sound suppressors, each type heretofore employed per se. One is a so-called "mixer" (really a frequency changer) which consists, for example, of a plurality of small, discrete and separate nozzles or pipes at the exhaust orifice. Among other disadvantages, these nozzles incorporate a rather significant amount of "wetted surfaces" which materially augment the drag of the engine. In the second type of conventional suppressor, misnamed an "ejector," an attempt is made to directly and completely mix the emerging exhaust with the ambient air right at the trailing edge of the unmodified generally circular nozzle. In such devices, there is no significant or effective shift into less ob-

jectionable high frequencies, though some reduction is somehow effected in sound power.

Each of these types has its disadvantages but we have discovered that by means enabling combining these two principles or types, effective noise reduction with minimum concomitant drag and loss of thrust are achieved for jet engines, whether they be turbo-compressor or ram jets.

The present combination first subdivides the unbroken, cylindric main exhaust, initiating mixing the subdivisions thereof with the secondary air, and for one thing, at once shifts it into the rapidly decaying higher frequencies and attenuates the velocity. Discrete "final" mixing means of a novel type are movably mounted aft of the tail pipe and cooperate with these subdivisions.

The invention contemplates, among other things, the combination in a jet engine, of a fixed, but fimbriated and enlarged integral and continuous perimeter, "frequency shifter or changer," occupying the entire rear portion of the tail pipe and built thereinto; with a longitudinally shiftable, or retractable and protractable, mixing inducer, or, in the vernacular, an injector, preferably of the retractable, "hollow barrel" type. The "single-piece" frequency-shifter consists essentially of a plurality of radial corrugations also having longitudinal extent built integrally with the tail pipe and defining lobes extending radially of the tail pipe and alternating with longitudinally extending flutings. Thus, in cross-section, the tail pipe is petallate in shape, much in the manner of a daisy.

The invention thus provide, among other things, an improved frequency shifter, which, by virtue of its continuous but fimbriated, and augmented perimeter, minimizes the wetted surface-drag and interference drag of the previous types of such article and concomitantly minimizes the thrust-loss of such devices. It also provides an improved final "mixer" in the form of a novel inducer and a novel combination of this "daisy" type frequency "changer," with the inducer. The inducer itself is also provided with improved thrust augmenting means.

When retracted over the engine's aft portion, as in flight, the inducer serves as a muffler for the sound waves radiating from the engine. At certain speeds of the airplane, also, the induction of a portion of the ambient airstream around the entering edge of the protracted inducer and into the inducer does, by virtue of the airstream pressure-distribution thereon, produce a slight net forwardly directed unbalanced force which, in certain speed ranges, actually augments the thrust of the engine a certain amount.

The inducer also preferably includes a thrust-reversing means, as of the clam-tong, Pelton bucket type.

In order to render these, and other, concepts more concrete and readily apprehensible, the presently-preferred form thereof is illustrated in the accompanying drawings, in which:

FIG. 1 is a perspective view of an airplane having jet propulsion plants incorporating this invention;

FIG. 2 is an enlarged fragmentary side view of one of these power plants, the inducer being retracted;

FIG. 3 is a similar view, the inducer being protracted and being shown in longitudinal central section, along with means for moving it and for operating the thrust reverser;

FIG. 4 is a view, partly in section and partly in plan, of the device with the inducer retracted;

FIG. 5 is a similar view with the inducer protracted and with the thrust-reverser inoperative;

FIG. 6 is a similar view with the thrust-reverser in operation;

FIG. 7 is an enlarged vertical fragmentary sectional view on line 7—7 of FIG. 3;

FIG. 8 is a view along line 8—8 of FIG. 2; and

FIG. 9 is a detailed longitudinal sectional view of the

valve means controlling the flow of compressed fluid for operating the thrust-reverser.

The invention is depicted as incorporated in a transport airplane 12, the wings 13 of which mount four jet propulsion units 14, here indicated as of the turbo-compressor jet-reaction type.

These engines are mounted to pylons 15 which extend forwardly from certain loci on the leading edge of the wing, a portion of each pylon extending chordwise of the lower surface of the wing and each pylon having the aft portion of its lower edge 17 unoccupied by any structural portion of the engine.

This edge-portion 17 is occupied by a track 18 fixed thereto in longitudinally extending position, the track being shown in side views in FIGS. 2 and 3 and in transverse section in FIG. 7.

As shown in side views in FIGS. 2 and 3 and in longitudinal section in FIG. 9, an impact-operated air-valve group 20 is mounted to the lower, aft edge of the track group for operating the thrust reverser's buckets, later described and in a mode hereinafter particularized.

Suspended rollably from track 18, for powered movement from an aft-located, or protracted, position, to a forwardly-located, or retracted position, is an inducer group 22. In its protracted position, one purpose of this inducer group is to hasten the mixing of the airstream enveloping the engine with the exhaust gases at the aftmost periphery, or fimbriated perimeter, of the air and exhaust orifice or frequency-changer, 24, later described. It does so essentially by creating a lowered-pressure zone at this forward perimeter and entraining the airstream aftwardly and convergently toward the longitudinal center line of the mixer-inducer combination, in conjunction with the so-called "Coanda" effect of the "bullet," or core, 27, later particularized. The principle and rule of action of this combination mixer, bullet and inducer involve a diminution of the "thickness ratio," an increase of the "area ratio" and an increase of the exit perimeter for a predetermined outside diameter, or envelope-diameter, of the aftmost edge of the nozzle by means of the present combination.

The thickness ratio is herein defined roughly as the ratio of the diameter or lateral extent of one of the multiplicity of streams into which the exhaust is herein divided to the diameter of the previously undivided cylindric single-stream exhaust of an engine of the same size of the prior art. The area ratio is roughly defined as the ratio of the area of the smallest circle that circumscribes a subdivided jet stream herein to that previously circumscribing the undivided cylindric jet stream of an engine of the same size of the prior art.

As a consequence of this diminution of thickness ratio, the frequency of the sound generated by the jet exhaust will be raised. High frequency sound waves are more susceptible (1) to scattering and (2) to absorption or "decay" than are lower frequency waves. Also, if the exhaust remains in the low frequency range, its noise remains obnoxious. Scattering spreads the polar peak and lowers same. The polar peak is found about 30° from the jet axis in the direction of efflux. Absorption of sound increases with distance of travel from the source and thus increases the attenuation, or damping, of the sound. This absorption-attenuation effect is superimposed upon, or added to, the ordinary attenuation that occurs according to the law of the inverse square of the distance.

The present increase in the area ratio and increase of exit-perimeter increases the rate of momentum-diffusion and the latter decreases the jet velocity and raises the mass flow rate and lowers the total noise-power of the exhaust. The inducer further aids this momentum diffusion by lowering the pressure at the aftmost edge of the nozzle, thus inducing or entraining into the exhaust gases, a secondary airstream which, with the inducer protracted, is drawn out of the enveloping ambient air and in be-

tween the lobes of the "daisy" type mixer and entrained into the inducer. Thereby, not only is the original velocity of the outer "envelope" of the secondary airstream around the engine amplified but, because the total jet is augmented, a small but definite percentage of gain over the static thrust of the engine is achieved.

The inducer, in its protracted position, also serves to present the sound waves from radiating laterally until the combined stream reaches the rear exit of the inducer, where the sound power has been greatly reduced.

The nozzle group 24 terminates rearwardly in a plurality of peripheral "distortions," or fimbriations, of the conoidal rearward surface of the tailpipe and these fimbriations configure and shape a nozzle of a given circumscribing diameter so as to provide a larger but integral perimeter thereon, within a conventional size circle, than otherwise deemed feasible. Essentially, therefore, the nozzle is transformed into a frequency changer comprising radiating lobes alternating with flutings, the lobes also having extension longitudinally of the tail pipe. It is also contemplated that, in order to prevent pressural distortion of these lobes out of their critical shapes, in each lobe the opposite radially extending walls may, if desired, incorporate tie rods, not shown, or each lobe may, by means of these tie-rods, be given a tension-produced shape, not shown, somewhat resembling a link of sausages; that is the lobe may be subdivided into smaller lobes of more truly circular cross-section than the petalate lobes, with a tie-rod, not shown, being transversely positioned between each of the adjacent sub-lobes. Preferably, these tie-rods would not lie in the transverse plane of the trailing edge, but at a small distance upstream from said edge.

The area-curve of this novel nozzle takes a sharp drop near the trailing edge thereof.

Thus the frequency shifter is a fixed, fimbriated one configured to also initiate mixing by the novel principle of momentum diffusion, for effecting frequency shifting and mixing-initiation substantially at the trailing edge of the nozzle.

The momentum diffusion effect is furthered by both convection transfer and conduction transfer, the convection effects being instituted by the novel turbulence, the conduction effects being at least aided, if not instituted, by augmentation of the total perimeter circumscribed by a circle only slightly larger than that of previous jet nozzles for the same-rated engine.

The transverse dimension of each lobe of the fimbriated exit profile is relatively small and an elevation of sound frequency results therefrom, with the aforesaid advantages. More specifically, the replacement of the single large-pipe nozzle of the prior art with the multiplicity of lobes reduces the "characteristic" length or thickness of the jet by a factor called the thickness ratio and since herein the mixing is substantially complete at a distance rearwardly equal to no more than ten times the diameter of a lobe, the mixing length concomitantly is decreased in the same ratio. This results in a concomitant reduction in the length of inducer required and a corresponding reduction in the total length of the nozzle group.

Generally, therefore, the invention transforms a "solid," or undivided, high velocity jet stream into a wide, low velocity stream or bundle of small streams as quickly as feasible, thus increasing the mass-flow, for thrust equals mass flow times velocity, momentum conservation keeping it constant.

By virtue of these facts, both the length and diameter of the inducer can be decreased below that expectable.

The combination thus has a somewhat unexpectedly low drag at high speeds, even when protracted; as well as possibly adding slight thrust when protracted, at certain critical speeds of the craft. In fact, an inducer of a length only about twice its own diameter may, by virtue of these principles, be employed herein.

The inducer, in the preferred form herein shown, is a

hollow frusto-conoidal body tapering from front to rear. The exterior surface of this conoidal body is outwardly bowed in streamline shape from front to rear and the surface that renders the body hollow and defines the mixing chamber also tapers from front to rear, the upper portion of this surface tapering curvedly from front to rear. The lower portion of this surface is rectilinear in section but also tapers from front to rear. Thus, the mixing chamber has a relatively large entrance opening and a smaller exit opening.

The circular base of the inducer, in operation thereof as herein shown, immediately rearwardly of the trailing edge of the frequency shifter, but this position is not essential. It may be located from slightly rearward of said trailing edge to well forward thereof. The important factor is the longitudinal extent of the inducer from the beginning of the mixing zone to the rear exit of the inducer.

The invention contemplates that the aft portion of the tailpipe be constructed to constitute a frequency-shifter by formations other than those having the specific shapes and arrangements herein shown by way of example.

In any case, the inducer length is preferably, though not exclusively, of the order of twice its maximum diameter, and its wall is, like that of a Townend ring, hollow and streamlined, having the shape of an airfoil section rotated about the longitudinal centerline thereof. The lower peripheral portion thereof has a longitudinally extending excrescence that houses certain thrust-reverser operating mechanism, later described. The forward edge, or rim, of the inducer, all around, has an airfoil section's leading edge-shape in order to provide thrust thereby at certain airspeeds.

The aftmost edge, or rim, of the inducer is sharp or acute, in order to minimize turbulence thereat.

The bullet, or core, 27 of the nozzle-group is mounted coaxially of the nozzle 24 and extends rearwardly from the aftmost flange of the engine itself to an optimum point, determined by experiment, lying in the forward portion of the protracted inducer-group, as best seen in FIG. 3. The bullet is generally conoidal in shape with a circular base A, a conical, point aft end B¹, and a re-entrant surface or concavity, C, intermediate the base and apex. The bullet thus defines with the nozzle wall 24A an annular passage, B, which varies in radial extent, or thickness, along the coextensive lengths of the bullet and nozzle wall.

The chief purpose of this configuration of the bullet and the wall 24 is to form a sort of diffusion chamber C¹ for the engine exhaust until these gases reach the exit periphery of the nozzle. The configuration thus controls the expansion of the exhaust gases, and the radial contraction of the bullet intermediate its ends, locally slows the exhaust somewhat, by expansion-diffusion and thereby reduces the friction losses therein which would result from the cumulative effects of its undiminished velocity.

Aftward of this "dip" in the profile of the bullet, the exhaust gases are constrained to travel centerwardly and longitudinally by the entraining and induction effects of the protracted inducer group. Otherwise, the entire quantum of the exhaust gas stream might expand into the outermost, arcuate portion of the lobes of the frequency-changer, none of it mixing, at the exit periphery, or edge, of the "daisy," with the secondary airstream entrained into the channels between the lobes of the daisy and following the sides and bottoms of the corrugations that define this exit periphery.

The "daisy" or frequency changer, is, of course designed or "tuned" with the bullet which is adjusted longitudinally until its apex lies at that point inside the protracted inducer whereby the optimum diffusion and centerward-entraining effects of the bullet upon the exhaust gas annular stream are achieved. By these means also, the "conical" expansion of the exhaust stream as it leaves the mixer is constrained sufficiently to prevent such a

degree of expansion as would reduce the net axial velocity of the jet below the desired sonic velocity, thereby to minimize thrust-loss.

It is to be noted that the inducer group entrains a portion of the main airstream enveloping the engine group, dragging it longitudinally along the frequency-changer in an annular form. Most of this secondary sub-airstream flows in between the lobes 28, in channels 30. There thus may be two components of the ambient airstream envelope mixing with the sub-divided exhaust gas streams at the aft "rim" of the mixer. These are not sharply separated and the former is much accelerated by the action of the latter.

The entire inducer group is constructed and arranged for retraction forwardly over the engine itself, leaving the nozzle-group exposed, as in FIG. 2, and for protraction aftwardly into the position shown in FIG. 3. When same is retracted, as is usually, but not exclusively, the case in flight, some decrease in the drag of the propulsion unit is achieved with a negligible loss in thrust, at certain speeds. Naturally in cruising flight no need for thrust-reversal is contemplated, so that loss of this function in the retracted position is of no consequence. When the inducer group is protracted, as in the ground run-up, take-off and landing operations of the aircraft, the configuration greatly enhances the silencing, or exhaust sound-suppressing effects of the apparatus. It has been ascertained, however, that even when protracted in flight, the thrust gain achieved by this configuration at certain speeds more than overbalances the increased drag of the configuration, under certain circumstances.

For retracting and protracting the inducer group, a mechanism is provided that includes a double-acting hydraulic cylinder 33 mounted on the pylon, to the piston rods of which double-acting cylinder an endless cable 36 leads over pulleys 34, the lower run of the cable being connected intermediate its ends to the upper periphery of the inducer. The latter is provided with rollers 35, as best seen in FIG. 7 that rollably support the inducer-reverser group on the longitudinally extending track 18. This mechanism is operated by conventional control means, not shown, but located in the crew's compartment.

On the diametrically opposite peripheral portion of the mixer there is provided a stabilizing track 37, longitudinally extending the full length of the retraction path of the inducer, as shown in FIG. 3, for cooperation with the inducer-reverser group so as to constrain it to move in balanced fashion, forwardly and backwardly. To this end, the group 22 bears a stabilizing arm 39 which, at its aft end, is pivoted to the forward edge of the inducer and which bears a roller 38 for engaging 37. The principle and action of this particular mechanism are self-explanatory.

For use in minimizing the landing-run, a special thrust-reverser system or configuration is provided. It includes, as shown in FIGS. 3-6, inclusive merely representationally, a pair of identical vanes or baffles 40, here shown as specially modified Pelton buckets, normally disposed for "clam-tong" action in diametrically opposite openings 47 in the wall of the inducer, these loci lying on the horizontal centerplane of the inducer. The openings are covered in the retracted position by aftwardly extending portions of the nacelle skin for streamlining purposes. Each diagrammatically represented bucket 40 may comprise an arcuate shell 32 and a horizontal plate or arm 49 by means of which the bucket is pivotally mounted to the inducer. The pivot 43 of each bucket is located on the geometrical center of the arcuate outer shell of the bucket, but the operating link therefor is offset laterally outwardly as in FIG. 3 from this pivot, in order to provide proper kinematics for enabling the bucket to fail safe, or close into the recesses, by means of exhaust gas or aerodynamic pressure, upon failure of the actuator or its linkage.

When the buckets are protracted, as shown in FIG. 6, the gases from the engine and the entrained ambient air are directed against the buckets and thence out and forwardly through openings 47. The added mass of the entrained air increases the effectiveness of the reverser over the prior art types in which only the engine exhaust gases are so used.

Operating mechanism for the buckets includes a pivot axis 44 for a link 43 connected to the piston rod 42 of a double-acting hydraulic cylinder 132 mounted in the lower, "airfoil section" wall of the inducer. Fluid line 52, FIG. 9, leads to a source of pressure fluid, not shown, but located at a suitable station in the aircraft. This fluid is preferably, though not mandatorily, compressed air. A control and locking valve 200 is in series in the outlet line 45 of the compressed air conduitry, as shown in FIG. 9. It is a three-way valve provided with a 3-position lever 201. In neutral, this lever causes the valve core (not shown) to block air flow either into or out of the bucket-operating cylinder, thus to hold the buckets in thrust reversing or retracted position. With the lever to the right, air flow into this cylinder occurs through pipe 202 and with lever to the left, airflow into the cylinder occurs through pipe 203. In each instance, the valve connects the opposite pipe to exhaust out of the valve body. However, other appropriate air-flow control means are also contemplated by the invention.

Intermediate the source of pressure fluid and the cylinder 132 and interposed in the line 45-52 is a control valve group 20 mounted to the underside of track 18 and enclosed in a longitudinally divided fairing. The fairing has an aft portion 60 fixed to the track and a forward portion 61 pivoted to the track.

The valve itself is comprised of a forward portion 65 carried by the wall of the inducer and therefore travelling forward and aft with the inducer, and a rearward portion 66 stationarily fixed to the track 18. In its rearward travel, the forward portion of the valve rides against the pivoted portion 61 of the fairing and raises same as shown in solid lines in FIG. 9, whereas the reverse action occurs in the forward travel of this valve portion.

Valve-portion 65 includes a hollow, rearwardly extending impact fitting 65A into the forward end of which the air duct 45 taps. The fixed, stationary portion 66 of the valve group includes a casing 64 into which the upper run of the air-line 52 is tapped. The casing includes a longitudinal hollow or bore 67, divided transversely, near its forward end, by an apertured partition 68. Aft of this partition a helical compression spring 71 is disposed coaxially thereof, the compression being variable by means of a set nut 72. Mounted coaxially in the apertured partition is a ported and shouldered tube 73. The radially extending shoulder 74 on the tube bears against the forward end of the coiled spring and is normally urged thereby against the partition. The aft ports 70 of the ported tube are separated normally from communication with the forward ports 75 by means of a baffle 76 which extends across, and entirely closes, the median portion of the tube. Between the apertured partition 68 and the front wall 150 of the casing of the rear "half" of this impact valve these two radially extending surfaces define annular chambers 100 each of which is of sufficient extent longitudinally to encompass each of the sets of ports, 70 and 75, when the tube is rearwardly urged by the contact of the front "half" of the valve with the rear "half" thereof. When the tube is urged forwardly by the spring, wall 150 cuts off communication between the two set of ports.

When the tube is urged rearwardly by air from 65 the rear end of the tube being open, and the inducer being rearwardly positioned, the air pressure in the rear portion of the casing enters the tube longitudinally, passes through the rear ports 70 and outwardly into the annular chamber 100 and thence forwardly into the forward ports 75 where-

from it passes forwardly through the tube and into 65, both sets of ports lying at that time within the rear portion of the casing. From the hollow front half 65 of the valve the air passes to bucket-piston energizing line 45.

The purpose of the baffle 76 located medially of the tube is to prevent the rearward entrance into the spring chamber 67 of jet blast, which would be likely to vitiate the spring and "buck" the entering air pressure. The purpose of disposing both sets of ports at the same time within the housing 64 is to open communication between lines 52 and 45.

Initiation of retraction of the inducer will, of course "break" this compressed air connection by returning the parts to the positions shown in FIG. 9, allowing the air to exhaust to atmosphere from cylinder 32.

The center of pressure of each of the Pelton buckets is disposed inwardly, that is, toward the longitudinal center line of the inducer, from the axis of the bucket. The buckets will therefore "fail safe"; that is, if the operating mechanism thereof should become inoperative with the buckets disposed in meeting position in the interior of the inducer, they will not "jam" or become immobilized in this attitude but will upon augmentation of take off exhaust, be blown into respective nested positions in the inducer.

Although the secondary, induced flow airstream aforementioned, when mixing with the exhaust gases emanating from the lobes of the mixer, displaces the final mixing point or zone somewhat farther downstream beyond the rim of the inducer and does somewhat add initially and temporarily to the noisy turbulence and "tearing" of the airstream in this initial mixing zone, the peak-to-peak attenuation of sound in this region, as compared to that of the conventional, unimproved jet nozzle is of the order of several decibels. Finally, the sound level of the now mixed air-and-exhaust jet at its highest value, 30° off the jet axis, is at least 12-15 decibels less than that of a conventional jet engine. The noise intensity maximum is actually reduced by as much as 10 decibels at 40° from the jet axis. The thrust, even with the inducer extended is never reduced more than about 2% and can be augmented by about 1% by the favorable pressure distribution effected on the inducer's entering edge, at certain speeds of the craft.

The present jet-exhaust sound suppressor materially reduces the sound-induced vibration fatigue in the airplane's structure. When retracted, it incorporates no drag increase and little, if any, thrust loss. Disregarding the reverser structure and operating mechanism, the weight penalty of the device is not high. The present suppressor also materially reduces the weight and volume of sound-proofing material required between the skins of the fuselage.

Although for purposes of clarity and concreteness certain specific nomenclature, dimensions and materials have been illustratively included hereinabove, it is to be understood that such usage in no wise restricts the scope of the actual invention as defined by the following claims.

We claim:

1. In a jet propulsion plant having a tail pipe: airstream-and-exhaust inducer means of hollow tubular form mounted for forward retraction and aftward protraction coaxially of said tail pipe, said means surrounding the tail pipe when said means is retracted and said means lying rearwardly of the tailpipe when said means is protracted; exhaust exit apertures in the forward portion only of said inducer means and normally in closed condition; closure-and-baffle means normally closing said apertures, said closure means consisting of a pair of Pelton-wheel buckets each pivoted to the inner face of said inducer means near a plane passing through the longitudinal center line of said inducer, said buckets being so pivoted and arranged, with respect to said apertures as to swing rearwardly from their apertures closing position toward said center line of said inducer means so as to then lie entirely within the confines of the inducer means, said

buckets, in meeting position on said center line, extending transversely across said inducer means and then blocking the passage of exhaust gas axially through said inducer means, the meeting plane of said buckets being located downstreamwardly of said apertures and the buckets being semi-spheric so as to also direct said gas forwardly and outwardly through said apertures, thereby to reverse the thrust of said propulsion plants; the pivot of each of said Pelton wheel buckets being located on center with respect to the curved peripheral surface of the bucket; and a powered operating link attached to each bucket at a point other than said pivot and located offset from said pivot.

2. In a jet propulsion plant having a tail pipe: an airstream-and-exhaust inducer of hollow generally tubular form mounted for forward retraction and aftward protraction coaxially of said tail pipe, said means surrounding the tail pipe when said means is retracted and said means lying rearwardly of the tailpipe when said means is protracted; said inducer having walls of substantial thickness and having lateral exhaust apertures therein; spheric baffle means swingably mounted in said inducer and movable from a position closing said apertures to a position blocking passage of exhaust gas and air axially through said inducer and directing it laterally through said apertures to produce reverse thrust; said baffle means being generally semi-cylindric in shape to lie within the walls of said inducer in retracted, aperture-closing position; each of the baffle means being pivoted at its inner corner to the interior of the inducer, said pivot being on center with the spheric periphery of the baffle; and a powered operating link attached to each baffle means at a locus thereof which lies off center from said periphery and from said first pivot to constrain the baffle means to fail safe; whereby said inducer, with said baffle means retracted, may be retracted forwardly to surround said tail pipe without interference from said baffle means.

3. In an aircraft jet propulsion plant having a tailpipe: a fimbriated exhaust nozzle shaped in its rearward portion so as to divide the unbroken cylindric upstream portion of the exhaust stream emerging from the nozzle into a plurality of smaller streams emerging rearwardly from loci distributed around the peripheral rear edge of the nozzle; a substantially conoidal core extending coaxially of said nozzle and having its apex protruding rearwardly from said nozzle; said core at its portion located at the nozzle exit having a diameter less than the inside diameter of the nozzle so as to provide a substantially central annular exhaust stream surrounded by said smaller peripherally distributed exhaust streams; hollow tubular inducer means having a rearward portion thereof disposed coaxially rearwardly of said apex, said inducer means surrounding the tail pipe when said inducer means is retracted and said inducer means lying rearwardly of the tailpipe when said inducer means is protracted, the side walls of the forward portion of said inducer including a pair of diametrically opposed acutely forwardly directed openings therein; a pair of spherical-segment baffle means independently pivoted in the interior of said inducer means with the pivots of each baffle on center with the peripheral surfaces of the baffle means, the spheric segments normally occupying said apertures in said side walls; and power means for rotating the pair of spheric segments from their positions in said apertures into mutual contiguity in a position extending across a transverse dimension of said inducer means thereby to provide a thrust reverser, each of the contiguously positioned baffles individually deflecting all of the smaller streams striking the baffles into an outwardly and acutely laterally forwardly directed path passing through said lateral openings in the form of two discrete streams acutely angled to the aforesaid original annular stream and to the said original smaller streams, so as to obviate interference therewith of the deflected streams with the original streams, thereby to prevent turbulence-created low-frequency noise in said original smaller streams and in said original annular

stream, thereby to minimize the turbulence-created noise produced by reversing-use of said thrust reverser means.

4. In a jet engine propulsion plant having a tailpipe, the combination of: an exhaust nozzle having its rearward portion fimbriated so as to divide the upstream cylindric and unbroken exhaust stream into a plurality of emerging smaller streams; a conoidal core coaxial with said nozzle and defining a central annular exhaust stream; inducer means coaxial with said nozzle and normally extending rearwardly therefrom, said inducer means surrounding the tail pipe when said inducer means is retracted and said inducer means lying rearwardly of the tailpipe when said inducer means is protracted, said inducer means having streamlined side walls congruently disposable over the nozzle; acutely laterally angled apertures in the side walls of the forward portion of said inducer means; thrust reverser means pivoted in the interior of said inducer means and normally occupying said apertures; and means for moving said reverser means to mutually meet inside the inducer on a transverse dimension of said inducer means thereby to direct the exhaust laterally outwardly and forwardly of the inducer means and through said two apertures in two separate streams that cannot interfere with the exhaust streams from the fimbriated portion of the nozzle and with the annular cylindric central stream from the nozzle.

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