LETTERS TO THE EDITOR

ON AIR FLOW INDUCED BY HOVERING INSECTS

HARMONIC Oscillator Theory[1] and mass flow theory[2] have been proposed to compute the wingbeat frequency of insects and birds from the data of the body parameters. The calculated values are reported to be in good agreement with the observed values. The Helicopter Theory[3] has been extended to birds in order to obtain the information on velocity of air induced downwards due to the wingbeat, to assess the power requirements for flight, while the mass flow theory to assess the specific power and power cost of hovering[4]. It may be mentioned here that both the mass flow and helicopter theories are concerned with the rate of mass flow of air induced downwards through the wing disc when the flier is in its normal state of hovering, to find the reacting force that balances the gravitational force.

The rates of mass flow of air induced downwards are given by the following equations:

$$\frac{dm}{dt} = S_d \cdot v_{iz} \cdot \rho \qquad \text{(Helicopter theory)} \quad (1)$$

and

$$\frac{dm}{dt} = S_d \cdot B_{eff} \cdot \rho \cdot \frac{v_h}{2} \qquad \text{(Mass flow theory)} \quad (2)$$

where S_d = Discarea = $\pi L^2/4$ where L is wing span

B_{eff} = Effective breadth of the wing defined as $\dfrac{\text{Total wing area}}{\text{Wing span}}$

v_{iz} = The velocity of air induced downwards through the wing disc = $\sqrt{W/S_d \cdot 2 \cdot \rho}$ where W is the weight of the flier

ρ = The density of the medium in which the flier is hovering (0·0011 grams/cc)

v_h = The wingbeat frequency in the hovering state of flight.

It has been observed that the rates of mass flow given by equations (1) and (2) do not agree with each other. The (dm/dt) value from epuation (1) is always greater than its value from equation (2). The observed deviation is of the order of 70 80%. Hence an attempt has been made to obtain a proper expression for the rate of mass flow of air that agrees with the Helicopter theory. This paper presents the parameters that have to be considered for determining the rate of mass flow of air in hovering state of flight. The wingbeat frequency has been experimentally determined by the flight sound[5] and stroboscopic techniques in the case of four species of insects.

A Proposed Correlation

When the flier is in its normal state of hovering the rate of mass flow of air induced downwards through wing disc is proportional to

(1) Disc area $S_d = \pi L^2/4$, where L is wing span

(2) Effective wing breadth $B_{eff} = \dfrac{\text{Wing area}}{\text{Wing length}}$

(3) Frequency of wingbeat, v_h

(4) Density of the medium ρ in which it is hovering; and

(5) Fineness ratio[6] of the body $\gamma = \dfrac{\text{Body length}}{\text{Its max. breadth}}$.

Thus

$$(dm/dt)_M \; \alpha \gamma \cdot S_d \cdot B_{eff} \cdot \rho \cdot v_h$$

$$(dm/dt) = K \cdot \gamma \cdot S_d \cdot B_{eff} \cdot \rho \cdot v_h \qquad (3)$$

where K is a proportionality constant.

In the above expression all the parameters are observed under laboratoty conditions, for four species of insects. Table I shows the results of the rates of mass flow of air induced downwards using equations (1) (2) and (3). It is interesting to note that (dm/dt) values of equations (1) and (3) are in agreement with each other, whereas marked deviation is noticed in the case of equation (2).

The plot (Fig. 1), between the two rates of mass flow of air induced downwards as given by equations (1)

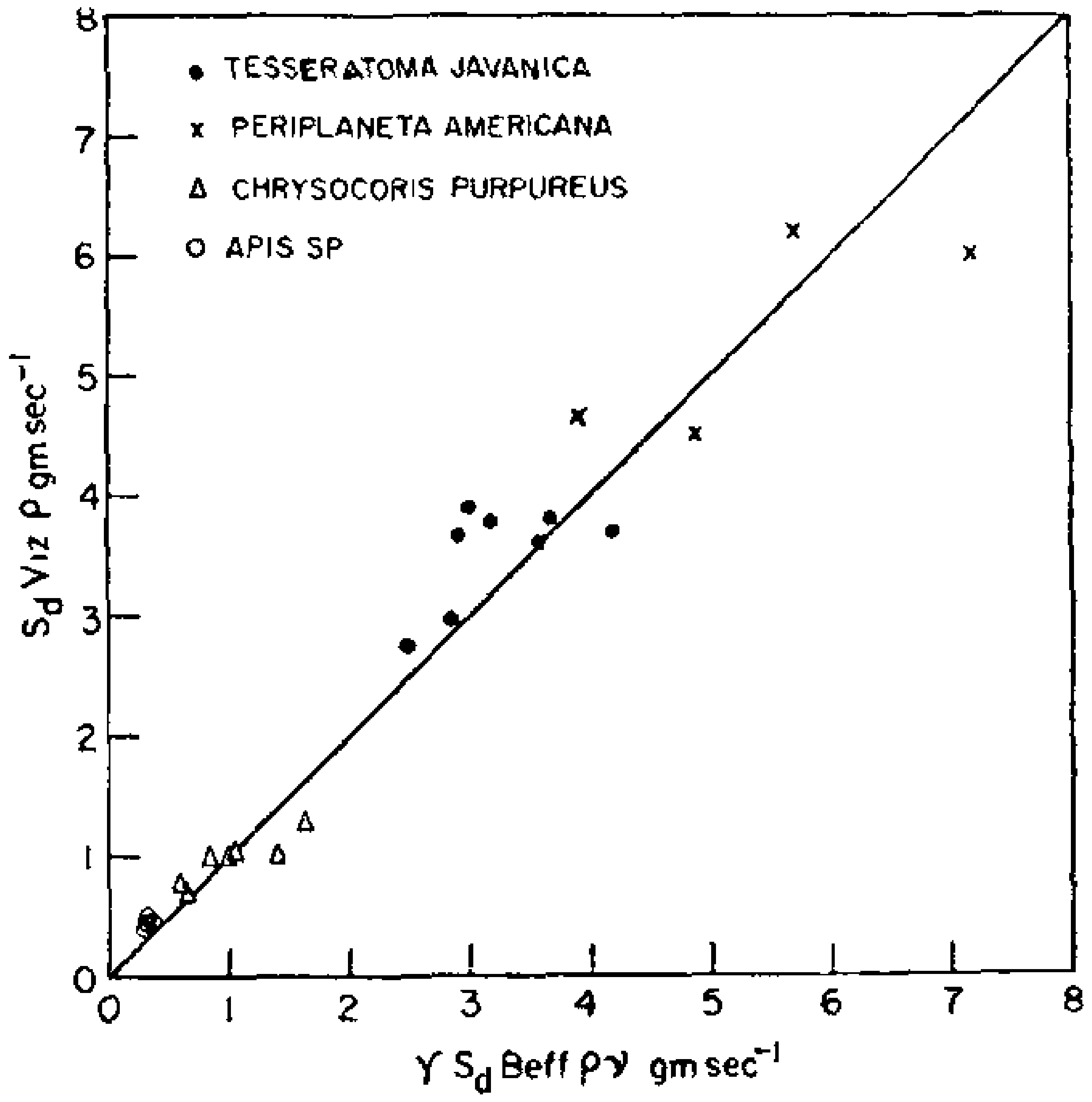

FIG. 1

TABLE I

Sl. No.	Flier	Mass of the flier M_f (gms)	Disc area S_d (cm^2)	Effective wing breadth B_{eff} (cm)	v_{ta} (cm/sec)	v_h (Hz)	(gm/sec)	Rate of mass flow of air		
								Eqn. 1 (gm/sec)	Eqn. 3 (gm/sec)	Eqn. 2 (gm/sec)
1.	*Tesseratoma javanica*	1·089	26	1·00	137	65	2·00	3·90	3·70	0·93
2.		0·998	27	0·84	129	68	2·00	3·80	3·40	0·85
3.		0·690	23	0·85	116	54	2·00	2·93	2·32	0·58
4.		0·763	22	0·92	123	67	2·00	3·00	2·98	0·75
5.		0·924	24	0·84	130	68	2·00	3·40	3·04	0·76
6.		0·899	24	1·01	128	73	1·90	3·40	3·70	0·97
7.		0·933	28	1·08	121	67	1·90	3·70	4·18	1·10
8.		1·047	26	1·03	132	67	1·90	3·80	3·75	0·99
9.	*Periplaneta ameribana*	0·920	41	2·00	100	20	2·70	4·50	4·86	0·90
10.		1·124	39	1·80	114	22	2·30	4·80	3·90	0·85
11.		1·287	53	2·10	104	22	2·65	6·06	7·14	0·35
12.		1·322	54	2·00	104	20	2·37	6·20	5·70	1·20
13.	*Apis* sp.	0·076	4·5	0·36	86	80	2·20	0·42	0·31	0·07
14.		0·075	4·2	0·34	90	80	2·70	0·42	0·34	0·06
15.		1·000	4·2	0·32	103	100	2·30	0·48	0·34	0·07
16.		0·073	3·8	0·32	92	90	2·60	0·38	0·32	0·06
17.		0·079	3·8	0·32	96	90	2·90	0·40	0·35	0·06
18.		0·093	5·3	0·31	88	80	2·30	0·51	0·33	0·07
19.		0·087	4·5	0·31	92	90	2·10	0·45	0·29	0·07
20.	*Chrysocoris purpureus*	0·224	8·6	0·54	108	70	2·30	1·02	0·82	0·18
21.		0·280	7·6	0·59	128	100	2·30	1·07	1·13	0·25
22.		0·160	7·6	0·52	98	65	2·30	0·82	0·65	0·14
23.		0·190	8·0	0·52	104	75	2·30	0·91	0·79	0·17
24.		0·360	9·1	0·65	133	110	2·30	1·33	1·65	0·36
25.		0·300	9·1	0·65	119	80	2·30	1·20	1·20	0,26
26.		0·310	7.6	0·62	134	120	2·30	1·12	1·43	0·31

and (3), shows a linear trend and the points scatter on a line with a slope of unity, suggesting that the value of proportionality constant K of equation (3), as unity.

This concept of rate of mass flow has an additional advantage over that given by helicopter theory, in the sense that, it is possible to obtain an expression for the induced acceleration of air for the hovering flight from a knowledge of the induced velocity and wing-beat frequency.

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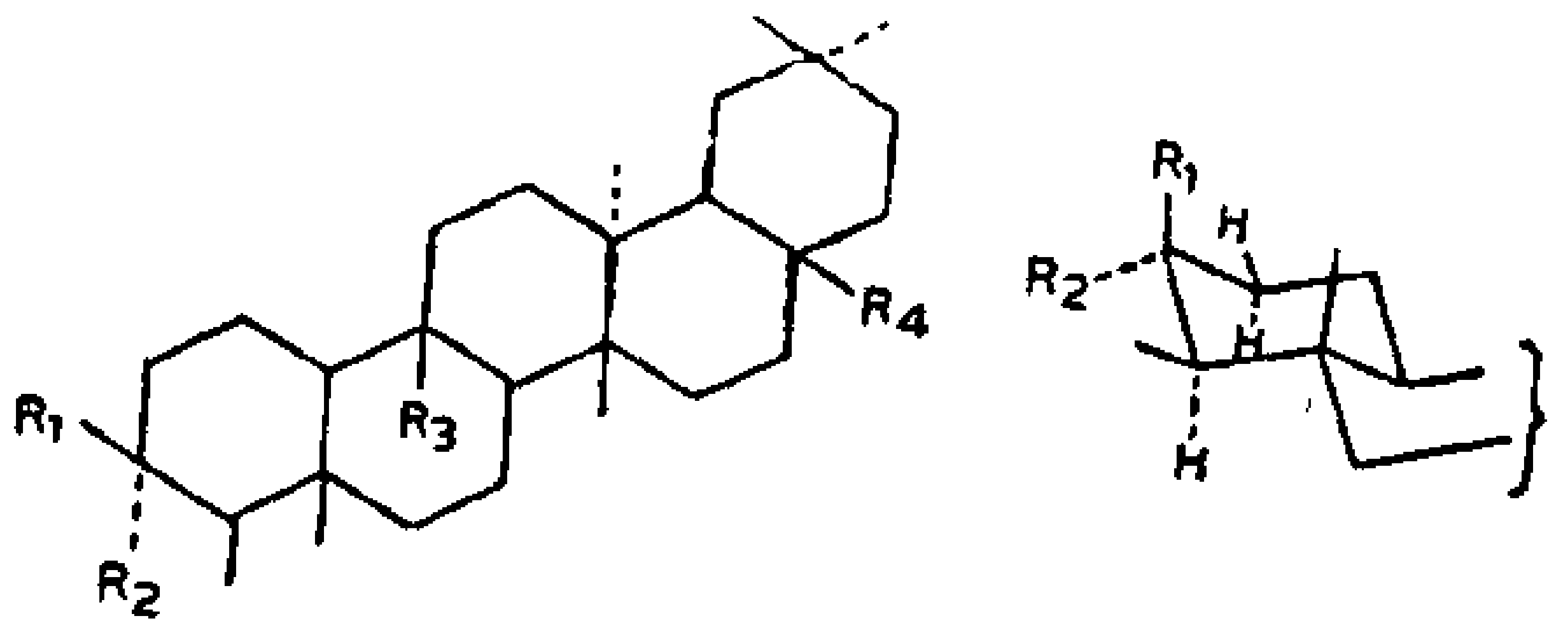
1. Crawford H. Greenwalt, *Proc. Am. Phil. Soc.*, 1960, **104**.
2. Puranik, P. G., Gopala Krishna, G, Adeel Ahmed and Chari, N., *Proc. Ind. Acad. Sci.*, 1977, **85**, Sec. B.
3. Pennycuick, C. J., *J. Exp. Biol.*, 1968, **49**, 527.
4. Gopala Krishna, G., Puranik, P. G. and Adeel Ahmed, *Proc. Conference on Mathematics in Social, Economic and Life Sciences, Mysore*, 1977.
5. Puranik, P. G. and Adeel Ahmed, *Ind. J. Expt. Biol.*, 1976, **14**, 279.
6. James Naidich, *Mathematics of Flight*, McGraw-Hill, 1943, p. 66.

CHARACTERISATION OF THE EPIMERIC 3α- AND 3β- FRIEDELAN-28- AND 25-DIOLS

Reduction of the 3-keto group in friedelin has been reported to give a mixture of friedelan-3α- and 3β-ols by several reagents[1,2]. In our recent paper we reported the isolation of a number of 3-keto friedelane derivatives from the bark of *Elaeodendron glaucum*[3]. In the characterisation of friedelan-3-on-28-al (canophyllal) (I)[4] and friedelan-3-on-25-ol (IV)[2], the corresponding 3α- and 3β- alcohols have been prepared as new derivatives by reduction of the 3-keto group with sodium borohydride and characterisation of these 3-epimeric alcohols by a study of their PMR spectra is presented now.

Canophyllal (I) on reduction with $NaBH_4$ in dioxan : methanol (1 : 1) solution yielded two epimeric alcohols, diol I, m.p. 248–50°; $[\alpha]_D + 20{\cdot}2°$, $R_f = 0{\cdot}46$ (benzene), ν_{max}^{nujol}: 3,495 cm^{-1} and diol II$^{\phi}$, m.p. 286–88°, $[\alpha]_D + 14{\cdot}8°$, $R_f = 0{\cdot}18$ (benzene), ν_{max}^{nujol}: 3,490 cm^{-1} in an yield of 55% and 25% respectively. The proton α- to the 3-hydroxyl in friedelane series appears as a multiplet, the $W_{1/2}$ value of which has been used to decide the stereochemistry at this position[5,6]. The smaller $W_{1/2}$ value (8 Hz) noticed for the multiplet 3–H signal centred at δ 3·70 in diol I suggests equatorial-axial and equatorial-equatorial couplings indicating it to be friedelan-3β (*a*), 28-diol (II) with 3α-equatorial hydrogen. The diol II with larger $W_{1/2}$ value (16 Hz) observed for its 3-hydrogen at δ 3·55 is therefore friedelan-3α (*e*), 28-diol (III) with 3β-axial hydrogen having axial-axial and axial-equatorial couplings. Govindachari *et al.*[4], reported only one diol by reduction of canophyllol with $NaBH_4$ and the physical characteristics of this agreed with diol I mentioned above.



I $R_1, R_2 = 0$; $R_3 = CH_3$; $R_4 = CHO$
II $R_1 = OH$; $R_2 = H$; $R_3 = CH_3$; $R_4 = CH_2OH$
III $R_1 = H$; $R_2 = OH$; $R_3 = CH_3$; $R_4 = CH_2OH$
IV $R_1, R_2 = 0$; $R_3 = CH_2OH$; $R_4 = CH_3$
V $R_1 = OH$; $R_2 = H$; $R_3 = CH_2OH$; $R_4 = CH_3$
VI $R_1 = H$; $R_2 = OH$; $R_3 = CH_2OH$; $R_4 = CH_3$

Similarly, friedelan-3-on-25-ol (IV) on reduction yielded the 3-epimeric diols, the major (50%)$^{\phi}$, m.p. 271–72°, $[\alpha]_D + 24{\cdot}2°$, $R_f = 0{\cdot}45$ (benzene-EtOAc, 9 : 1), ν_{max}^{nujol}: 3,490 cm^{-1} and the minor (30%)$^{\phi}$ m.p. 244–46°, $[\alpha]_D + 18{\cdot}5°$, $R_f = 0{\cdot}33$ (benzene-EtOAc, 9 : 1), ν_{max}^{nujol} 3,485 cm^{-1}. From the $W_{1/2}$ values of the 3-hydrogen, the major ($W_{1/2}$ = 6Hz, δ 4·00) is fixed as friedelan-3β (*a*), 25-diol (V) and the minor ($W_{1/2}$ = 12 Hz, δ 3·72) as friedelan-3α (*e*), 25-diol (VI). It is also noteworthy that the 3β (*a*)-hydrogen appeared slightly shielded, as could be expected, in both the diols (III) and (V) when compared with their respective epimers (II and IV).

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$^{\phi}$ New diols gave satisfactory analysis.

1. Brownlie, G., Spring, F. S., Stevenson, R. and Strachan, W. S., *J. Chem. Soc.*, 1956, p. 2419.
2. Courtney, J. L., Gascoigne, R. M. and Szumer, A. Z., *Ibid.*, 1956, p. 2119.
3. Anjaneyulu, A. S. R. and Narayana Rao, M., *Phytochemistry*, 1979 (In press).
4. Govindachari, T. R., Viswanathan, N., Pai, B. R., Ramdas Rao, U. and Srinivasan, M., *Tetrahedron*, 1967, **23**, 1901.
5. Jackman, L. M. and Sternhell, S., *Application of Nuclear Magnetic Resonance Spectroscopy in Organic Chemistry*, Pergamon Press, London, Second Edition, 1969.
6. Gunasekera, S. P. and Sultanbawa, M. U. S. *J. Chem. Soc. Perkin Trans. I*, 1977, p. 483.