

Astérisque

MÁRCIO G. SOARES

**Singularities of logarithmic foliations and connectedness
of the union of logarithmic components**

Astérisque, tome 323 (2009), p. 431-439

http://www.numdam.org/item?id=AST_2009__323__431_0

© Société mathématique de France, 2009, tous droits réservés.

L'accès aux archives de la collection « Astérisque » (<http://smf4.emath.fr/Publications/Asterisque/>) implique l'accord avec les conditions générales d'utilisation (<http://www.numdam.org/conditions>). Toute utilisation commerciale ou impression systématique est constitutive d'une infraction pénale. Toute copie ou impression de ce fichier doit contenir la présente mention de copyright.

NUMDAM

Article numérisé dans le cadre du programme
Numérisation de documents anciens mathématiques

<http://www.numdam.org/>

SINGULARITIES OF LOGARITHMIC FOLIATIONS AND CONNECTEDNESS OF THE UNION OF LOGARITHMIC COMPONENTS

by

Márcio G. Soares

To José Manuel Aroca on the occasion of his 60th birthday

Abstract. — We show that the singular locus of a logarithmic foliation may have components of any dimension between 0 and $n - 2$. Moreover, it is shown that the union of the logarithmic components of the space of codimension one foliations of $\mathbb{P}_{\mathbb{C}}^n$, of fixed degree, is connected.

Résumé (Singularités des feuilletages logarithmiques et connectivité de l’union des composantes logarithmiques)

On montre que le lieu singulier d’un feuilletage logarithmique peut avoir des composantes de dimension 1 à $n - 2$. On montre aussi que, dans l’espace des feuilletages de codimension un de $\mathbb{P}_{\mathbb{C}}^n$, de degré fixé, la réunion des composantes logarithmiques est connexe.

1. Introduction

In this note we treat two simple questions.

The first is to explore some properties of the singular locus of a projective logarithmic foliation. Our motivation for this is the result given in [6] which states that, for a generic logarithmic foliation of $\mathbb{P}_{\mathbb{C}}^n$, $n \geq 3$, the singular scheme only exhibits components of dimensions 0 and $n - 2$. We exploit this by considering non-generic logarithmic foliations, and by examining the possible dimensions of the components of their singular loci. It turns out that, for a non-generic such foliation, the singular locus may have components of any dimension between 0 and $n - 2$, with the only constraint that the dimension $n - 2$ is compulsory. On the other hand, we do not know if the isolated singularities, away from the polar divisors of the logarithmic form, which necessarily appear in case the foliation is generic (see Theorem 1.5 below), are persistent under a deformation into a foliation whose singular set admits components

2000 Mathematics Subject Classification. — 32S65.

Key words and phrases. — Logarithmic foliations, singularities.

Work partially supported by CAPES-DGU, FAPEMIG and Pronex/FAPERJ-CNPq (Brasil).

of dimensions ranging from 1 to $n - 3$. In this direction however, see Example 2.6 at the end of this article.

The second consists in showing that the union of the logarithmic components of the space of codimension one foliations of $\mathbb{P}_{\mathbb{C}}^n$, of fixed degree, is connected. This is true also for the rational components of fixed degree. It is perhaps worth remarking that this result resembles a foundational contribution, by R. Hartshorne [8], on the connectedness of the Hilbert scheme parametrizing the family of closed subschemes of $\mathbb{P}_{\mathbb{C}}^n$ with a fixed Hilbert polynomial.

We start by recalling some definitions and (known) results.

A codimension one holomorphic foliation \mathcal{F} of $\mathbb{P}_{\mathbb{C}}^n$ is defined by an integrable polynomial 1-form $\omega = \sum_{i=0}^n A_i(z) dz_i$, where each A_i is a homogeneous polynomial, say of degree $k - 1$, and such that ω contracts to zero by the radial vector field $R = \sum_{i=0}^n z_i \frac{\partial}{\partial z_i}$, that is, $\iota_R \omega = \sum_{i=0}^n z_i A_i(z) \equiv 0$.

Such 1-forms define global sections of $\Omega_{\mathbb{P}_{\mathbb{C}}^n}^1(k)$ and, since $\omega \wedge d\omega \equiv 0$, they make up a Zariski closed subset of $\mathbb{P}(H^0(\Omega_{\mathbb{P}_{\mathbb{C}}^n}^1(k)))$.

The degree of a foliation \mathcal{F} , $\text{deg } \mathcal{F}$, is the number of tangencies of the leaves of \mathcal{F} with a generic one-dimensional linear subspace of $\mathbb{P}_{\mathbb{C}}^n$. A simple calculation shows that $\text{deg } \mathcal{F} = k - 2$ if the 1-form defining \mathcal{F} has components of degree $k - 1$. We denote by $\text{Fol}(\mathbb{P}_{\mathbb{C}}^n; k)$ the space of codimension one holomorphic foliations of degree $k - 2$ of $\mathbb{P}_{\mathbb{C}}^n$.

A very interesting question is that of recognizing the irreducible components of $\text{Fol}(\mathbb{P}_{\mathbb{C}}^n; k)$ and to determine their dimensions and degrees. Results in this direction can be found in [4], [5] and [3].

Logarithmic foliations are defined as follows: given positive integers d_0, \dots, d_m , set $\underline{d} = d_0, \dots, d_m$ and $d = \sum_{i=0}^m d_i$. Consider the hyperplane

$$\mathbb{P}(m - 1, \underline{d}) = \{(\lambda_0, \dots, \lambda_m) \in \mathbb{P}_{\mathbb{C}}^m : \sum_{i=0}^m d_i \lambda_i = 0\}. \tag{1}$$

Define a rational map Ψ by

$$\begin{aligned} \mathbb{P}(m - 1, \underline{d}) \times \prod_{i=0}^m \mathbb{P}(H^0(\mathbb{P}_{\mathbb{C}}^n; \mathcal{O}(d_i))) &\xrightarrow{\Psi} \text{Fol}(\mathbb{P}_{\mathbb{C}}^n; \underline{d}) \\ ((\lambda_0, \dots, \lambda_m), (F_0, \dots, F_m)) &\longmapsto \left(\prod_{j=0}^m F_j \right) \sum_{i=0}^m \lambda_i \frac{dF_i}{F_i}. \end{aligned} \tag{2}$$

Note that $\iota_R \left(\prod_{j=0}^m F_j \right) \sum_{i=0}^m \lambda_i \frac{dF_i}{F_i} = \left(\prod_{j=0}^m F_j \right) \sum_{i=0}^m d_i \lambda_i \equiv 0$. Also, it's immediate that this form is closed (hence integrable).

The closure of the image of Ψ is the set $\text{Log}_n(d_0, \dots, d_m)$ of logarithmic foliations of type \underline{d} and degree $d - 2$ of $\mathbb{P}_{\mathbb{C}}^n$.

Let us recall the following result, due to Calvo-Andrade [2]:

Theorem 1.1. — *For fixed \underline{d} and $n \geq 3$, $\text{Log}_n(d_0, \dots, d_m)$ is an irreducible component of $\text{Fol}(\mathbb{P}_{\mathbb{C}}^n; \underline{d})$.*

Remark 1.2. — In case $m = 1$, $\text{Log}_n(d_0, d_1)$ is a component of $\text{Fol}(\mathbb{P}^n_{\mathbb{C}}; d_0 + d_1)$, called a *rational component*. This is because such \mathcal{F} 's are necessarily given by $\varpi = d_1 F_1 dF_0 - d_0 F_0 dF_1$, and they all admit a rational first integral, namely, $\frac{F_0^{d_1}}{F_1^{d_0}}$.

Let \mathcal{F} be a logarithmic foliation of $\mathbb{P}^n_{\mathbb{C}}$, $n \geq 3$, given, in \mathbb{C}^{n+1} , by the 1-form

$$\omega = \left(\prod_{j=0}^m F_j \right) \sum_{i=0}^m \lambda_i \frac{dF_i}{F_i} = \lambda_0 \widehat{F}_0 dF_0 + \dots + \lambda_m \widehat{F}_m dF_m. \tag{3}$$

where $F_i \in \mathbb{C}[z_0, \dots, z_n]$ is homogeneous of degree $d_i \geq 1$, $\sum_{i=0}^m d_i = d$, $\sum_{i=0}^m \lambda_i d_i = 0$ and $\widehat{F}_j = F_1 \cdots F_{j-1} F_{j+1} \cdots F_m$.

The singular set of \mathcal{F} is $S(\mathcal{F}) = \{z \in \mathbb{P}^n_{\mathbb{C}} : \omega(z) = 0\}$ and the fact that ω is integrable imposes the existence of codimension 2 components in $S(\mathcal{F})$ (see [9]).

It is immediate that $S(\mathcal{F})$ contains the union of all codimension two subsets $F_i = F_j = 0$.

Let $D_i = \{p \in \mathbb{P}^n_{\mathbb{C}} : F_i(p) = 0\}$ be the divisor associated to F_i .

Definition 1.3. — A logarithmic foliation given by $\omega = \lambda_0 \widehat{F}_0 dF_0 + \dots + \lambda_m \widehat{F}_m dF_m$ is said to be *generic* if

$$\begin{cases} F_i, i = 0, \dots, m, & \text{is irreducible} \\ \text{the } D_i\text{'s, } i = 0, \dots, m, & \text{are smooth and in general position.} \\ \lambda_i \neq 0, i = 0, \dots, m. \end{cases} \tag{4}$$

Remark that (4) defines a Zariski open subset of

$$\mathbb{P}(m - 1, d) \times \prod_{i=0}^m \mathbb{P}(H^0(\mathbb{P}^n_{\mathbb{C}}; \mathcal{O}(d_i))).$$

The following result was proven in [6]:

Proposition 1.4. — Let $\mathcal{F} \in \text{Log}_n(d_0, \dots, d_m)$ be given by $\omega = \left(\prod_{j=0}^m F_j \right) \sum_{i=0}^m \lambda_i \frac{dF_i}{F_i}$ and assume \mathcal{F} is generic. Then $S(\mathcal{F})$ has only codimension 2 and dimension 0 components.

Proof. — The proof of this is a simple argument, which we present here for the sake of completeness:

We will show that, if a point is non isolated in $S(\mathcal{F})$, then it lies in $D_i \cap D_j$ for some $i < j$. Indeed, let C be an irreducible component of $S(\mathcal{F})$ of dimension $1 \leq \dim C \leq n - 2$. By ampleness and general position, we may pick a point $p \in C$

lying in the intersection of precisely k of the divisors D_i , $1 \leq k \leq \min\{n, m + 1\}$. Let f_i be a local equation for D_i at p . Near p , the foliation \mathcal{F} is given by the 1-form

$$\varpi = f_0 \dots f_m \sum_{i=0}^m \lambda_i \frac{df_i}{f_i}.$$

Renumbering the indices we may assume $p \in D_0 \cap \dots \cap D_{k-1}$. The local defining equations $f_i = 0$ of the D_i 's, for $i = 0, \dots, k - 1$, are part of a regular system of parameters, i.e., df_0, \dots, df_{k-1} are linearly independent at p . Write $\tilde{g} = f_k \dots f_m$. Since $p \notin D_j$, $k \leq j \leq m$, we may assume \tilde{g} vanishes nowhere around p and write ϖ as

$$\varpi = f_0 \dots f_{k-1} \tilde{g} \left[\sum_{j=0}^{k-1} \lambda_j \frac{df_j}{f_j} + \sum_{i=k}^m \lambda_i \frac{df_i}{f_i} \right] = f_0 \dots f_{k-1} \tilde{g} \left[\sum_{j=0}^{k-1} \lambda_j \frac{df_j}{f_j} + \eta \right],$$

where $\eta = \sum_{i=k}^m \lambda_i \frac{df_i}{f_i}$ is a holomorphic closed form near p . Since η is closed, it is exact near p , say $\eta = d\xi$. Set $\vartheta = \varpi/\tilde{g}$. Then \mathcal{F} is defined around p by

$$\vartheta = f_0 \dots f_{k-1} \left[\sum_{j=0}^{k-1} \lambda_j \frac{df_j}{f_j} + d\xi \right] = f_0 \dots f_{k-1} \left[\lambda_0 \frac{d(\exp[\xi/\lambda_0]f_0)}{\exp[\xi/\lambda_0]f_0} + \sum_{j=1}^{k-1} \lambda_j \frac{df_j}{f_j} \right].$$

Set $z_0 = \exp[\xi/\lambda_0]f_0$ and $z_1 = f_1, \dots, z_{k-1} = f_{k-1}$. Since $u = \exp[\xi/\lambda_0]$ is a unit, we have that also z_0, \dots, z_{k-1} are part of a regular system of parameters at p . Now ϑ can be written as

$$\vartheta = \frac{z_0}{u} z_1 \dots z_{k-1} \left[\lambda_0 \frac{dz_0}{z_0} + \sum_{j=1}^{k-1} \lambda_j \frac{dz_j}{z_j} \right].$$

Thus \mathcal{F} is defined around p by the 1-form

$$\tilde{\vartheta} = z_0 z_1 \dots z_{k-1} \left[\lambda_0 \frac{dz_0}{z_0} + \sum_{j=1}^{k-1} \lambda_j \frac{dz_j}{z_j} \right] = \sum_{j=0}^{k-1} \lambda_j z_0 \dots \widehat{z_j} \dots z_{k-1} dz_j.$$

If $k = 1$, the above expression shows that the foliation is defined near p by dz_0 and then is non-singular at p . Hence we necessarily have $k \geq 2$. Note that the ideal of the scheme of zeros of $\tilde{\vartheta}$ (as well as of ω) near p is generated by the k monomials $z_0 \dots \widehat{z_j} \dots z_{k-1}$ with $0 \leq j \leq k - 1$. That is just the scheme union $\cup_{i,j} D_i \cap D_j$, for $0 \leq i < j \leq k - 1$. Thus C must be contained in $D_i \cap D_j$, for some $i < j$, and therefore C is an irreducible component of $D_i \cap D_j$ and $\dim C = n - 2$. \square

The main result of [6] is:

Theorem 1.5. — *Let \mathcal{F} be a generic logarithmic foliation of $\mathbb{P}_{\mathbb{C}}^n$ of type $\underline{d} = d_0, \dots, d_m$, given by $\lambda_0 \widehat{F_0} dF_0 + \dots + \lambda_m \widehat{F_m} dF_m$. Then the singular scheme $S(\mathcal{F})$ of \mathcal{F} can be written as a disjoint union*

$$S(\mathcal{F}) = Z \cup R \tag{5}$$

where $Z = \bigcup_{i < j} D_{ij}$ and R is finite, consisting of

$$N(n, \underline{d}) = \text{the coefficient of } h^n \text{ in } \frac{(1-h)^{n+1}}{\prod_{i=0}^m (1-d_i h)} \tag{6}$$

points counted with natural multiplicities.

It turns out that

$$N(n, \underline{d}) = \sum_{j=0}^n \binom{m-1}{j} \mathcal{W}_{n-j}(d_0-1, \dots, d_m-1), \tag{7}$$

where $\mathcal{W}_k(X_0, \dots, X_m)$ is the complete symmetric function of degree k in $m+1$ variables, that is, $\mathcal{W}_0 = 1$ and $\mathcal{W}_k(X_0, \dots, X_m) = \sum_{i_0+\dots+i_m=k} X_0^{i_0} \dots X_m^{i_m}$.

It follows that, whenever at least one $d_i \geq 2$, we have $N(n, \underline{d}) > 0$. Remark also that by (6) or (7), in case all $d_i = 1$, only for $n \geq m$ we have $N(n, \underline{d}) = 0$.

Proof. — The proof of this theorem is based on the fact that, if \mathcal{F} is a generic logarithmic foliation, then the codimension two part of its singular scheme is equal to the singular scheme of the normal crossings divisor $\bigcup_i D_i$. We can then use Aluffi’s formula ([1]) for the Segre class of $\bigcup_i D_i$. □

2. Deformations of generic logarithmic foliations

We start by stating some simple remarks, in the form we need. The first one is given in Fulton ([7], 8.4.13):

Remark 2.1. — *The hypersurfaces of degree d_j in $\mathbb{P}_{\mathbb{C}}^n$ are parametrized by $\mathbb{P}_{\mathbb{C}}^{M_j}$, where $M_j = \binom{d_j+n}{n} - 1$. Let $X = (X_0 : \dots : X_n)$ be homogeneous coordinates in $\mathbb{P}_{\mathbb{C}}^n$, $\mu_{(\ell)}^j$ homogeneous coordinates in $\mathbb{P}_{\mathbb{C}}^{M_j}$ and $\Phi_{d_j} = \sum \mu_{(\ell)}^j X^{(\ell)}$ the expression defining the universal hypersurface of degree d_j in $\mathbb{P}_{\mathbb{C}}^n \times \mathbb{P}_{\mathbb{C}}^{M_j}$. The incidence variety $\mathcal{V} \subset \mathbb{P}_{\mathbb{C}}^n \times \mathbb{P}_{\mathbb{C}}^{M_j}$ is defined by*

$$\mathcal{V} = \{(X, \mu^j) : \Phi_{d_j}(\mu^j, X) = 0\}.$$

\mathcal{V} is a smooth, irreducible (hence connected) subvariety of $\mathbb{P}_{\mathbb{C}}^n \times \mathbb{P}_{\mathbb{C}}^{M_j}$ of codimension 1. Let $\pi : \mathbb{P}_{\mathbb{C}}^n \times \mathbb{P}_{\mathbb{C}}^{M_j} \rightarrow \mathbb{P}_{\mathbb{C}}^{M_j}$ be the projection and consider its restriction to \mathcal{V} , $\pi|_{\mathcal{V}} : \mathcal{V} \rightarrow \mathbb{P}_{\mathbb{C}}^{M_j}$. The fiber D_{μ^j} of $\pi|_{\mathcal{V}}$ over μ^j is the corresponding hypersurface. Notice that the generic fiber is an irreducible, non-singular hypersurface of degree d_j .

Next we have

Remark 2.2. — *An irreducible hypersurface of degree $d \geq 2$ in $\mathbb{P}_{\mathbb{C}}^n$, $n \geq 3$, may have a singular set of dimension $0, 1, \dots, n-2$. Examples of such are given by:*

$$P_k(z_0, \dots, z_n) = z_0^d + z_0^{d-1}(z_1 + \dots + z_k) + z_{k+1}^d + \dots + z_n^d$$

where, for each $1 \leq k \leq n - 1$, $\text{sing}\{P_k = 0\} = \mathbb{L}^{k-1}$, a linear subspace of $\mathbb{P}_{\mathbb{C}}^n$ of dimension $k - 1$.

2.1. Bifurcations of singular sets

Theorem 2.3. — *A generic foliation $\mathcal{F} \in \text{Log}_n(d_0, \dots, d_m)$ admits a one-parameter deformation, say \mathcal{F}_t , either real analytic or holomorphic, into an $\mathcal{F}_0 \in \text{Log}_n(d_0, \dots, d_m)$, such that $S(\mathcal{F}_0)$ has components, at our choice, of any dimension from 0 up to $n - 2$, provided at least one $d_j \geq 2$. Moreover, if t is real then \mathcal{F}_t may be taken generic for all $t \neq 0$ whereas, in case t is complex, \mathcal{F}_t may fail to be generic only for a finite set of non-zero parameters t .*

Proof. — Let \mathcal{F} be a generic foliation in $\text{Log}_n(d_0, \dots, d_m)$, given by

$$\omega = \lambda_0 \widehat{F}_0 dF_0 + \dots + \lambda_m \widehat{F}_m dF_m$$

and reorder the indices in such a way that $d_0 \leq \dots \leq d_m$. Let j be the smallest index such that $d_j \geq 2$ and $(\pi|_{\mathbb{V}})^{-1}(\mu_j) = D_{\mu_j} = \{F_j = 0\} = D_j$ (see Remark 2.1). By Remark 2.2, we can choose a $\tilde{\mu}_k^j$, in the discriminant locus Δ_{d_j} of $\pi|_{\mathbb{V}}$, such that the hypersurface $D_{\tilde{\mu}_k^j}$ is irreducible and has as singular set a linear subspace $\mathbb{L}^{k(d_j)}$ of dimension $k(d_j)$, at our choice, with $0 \leq k(d_j) \leq n - 3$.

Choose a real analytic path, $\gamma_j : [0, 1] \rightarrow \mathbb{P}_{\mathbb{C}}^{M_j}$, such that $D_{\gamma_j(1)} = D_{\mu_j}$, $D_{\gamma_j(0)} = D_{\tilde{\mu}_k^j}$, $D_{\gamma_j(s)}$ is irreducible and smooth for $s \neq 0$, $D_{\gamma_j(s)}$ is in general position with $D_0, \dots, \widehat{D_j}, \dots,$

D_m , for $s \neq 0$, and $\mathbb{L}^{k(d_j)}$ is in general position with $D_0, \dots, \widehat{D_j}, \dots, D_m$. The existence of such a path is assured by the following procedure: start by choosing a $\tilde{\mu}_k^j$ such that both $\mathbb{L}^{k(d_j)}$ and $D_{\tilde{\mu}_k^j}$ are in general position with $D_0, \dots, \widehat{D_j}, \dots, D_m$. Next, the set of hypersurfaces of degree d_j which are in general position with $D_0, \dots, \widehat{D_j}, \dots, D_m$ correspond to a Zariski open set \mathcal{A}_1 in $\mathbb{P}_{\mathbb{C}}^{M_j}$, and so does the set of smooth irreducible hypersurfaces, call it \mathcal{A}_2 , which is the complement of the discriminant of $\pi|_{\mathbb{V}}$. The complement of $\mathcal{A}_1 \cap \mathcal{A}_2$ has complex codimension ≥ 1 and we have the real path γ . Along the path the foliation is given by

$$\omega_{\gamma(t)} = F_0^t \dots F_j^t \dots F_m^t \left(\lambda_0 \frac{dF_0^t}{F_0^t} + \dots + \lambda_j \frac{dF_j^t}{F_j^t} + \dots + \lambda_m \frac{dF_m^t}{F_m^t} \right) \text{ with } F_i^t \equiv F_i, i \neq j.$$

We now repeat the above argument for d_{j+1} and so on. Of course, the $n - 2$ dimensional components of $S(\mathcal{F}_0)$ are given by $\{F_i^0 = F_j^0 = 0\}$, $i < j$.

A holomorphic deformation can be obtained as follows: let μ_j and $\tilde{\mu}_k^j$ be as above and take the line ℓ in $\mathbb{P}_{\mathbb{C}}^{M_j}$ passing through them. Going from μ_j to $\tilde{\mu}_k^j$ along ℓ gives at most $\text{deg } \Delta_{d_j}$ points which correspond to singular hypersurfaces, plus a finite number of points at which $D_{\tilde{\mu}_k^j}$ fails to be in general position with $D_0, \dots, \widehat{D_j}, \dots, D_m$. \square

2.2. Deformations into other logarithmic components of the same degree

Here we consider logarithmic components to which $\text{Log}_n(d_0, \dots, d_m)$ specializes.

From Remark 2.1 we deduce the following: let H be an irreducible homogeneous polynomial of degree d_j which defines a smooth projective hypersurface $\{H = 0\}$ and $G = G_1 \dots G_\ell$ be a reducible homogeneous polynomial of degree $d_j = \deg G_1 + \dots + \deg G_\ell$. Then we can find a real analytic one-parameter family \widetilde{D}_s of smooth irreducible hypersurfaces, whenever $s \neq 0$, such that $\widetilde{D}_1 = \{H = 0\}$ and $\widetilde{D}_0 = \bigcup_{i=1}^{\ell} \{G_i = 0\}$.

Now, given a non-negative integer d , let $P(d)$ be the number of unrestricted partitions of d , for which we adopt the natural representation, that is, $\underline{\sigma}_d = i_1, \dots, i_q$ means $d = i_1 + \dots + i_q$. It's well known (Euler's formula) that

$$\frac{1}{\prod_{i=1}^{\infty} (1 - \xi^i)} = \sum_{d=0}^{\infty} P(d) \xi^d.$$

With this at hand we have

Theorem 2.4. — *Let $\mathcal{F} \in \text{Log}_n(d_0, \dots, d_m)$ be a generic logarithmic foliation given by*

$$\omega = \left(\prod_{j=0}^m F_j \right) \sum_{i=0}^m \lambda_i \frac{dF_i}{F_i} = \lambda_0 \widehat{F}_0 dF_0 + \dots + \lambda_m \widehat{F}_m dF_m.$$

For each degree d_j , let $\underline{\sigma}_{d_j} = i_1, \dots, i_{q(d_j)}$ be any partition of d_j , $0 \leq j \leq m$. Then, there is a real analytic one-parameter deformation \mathcal{F}^s of \mathcal{F} such that $\mathcal{F}^1 = \mathcal{F}$ and $\mathcal{F}^0 \in \text{Log}_n(\underline{\sigma}_{d_0}, \dots, \underline{\sigma}_{d_m})$.

Proof. — Let $\underline{\sigma}_{d_j} = i_1, \dots, i_{q(d_j)}$ and choose a real analytic one-parameter deformation of F_j, F_j^s , such that $F_j^1 = F_j$ and $F_j^0 = G_{i_1} \dots G_{i_{q(d_j)}}$. Since

$$\lambda_j \frac{dF_j^0}{F_j^0} = \lambda_j \sum_{i_1}^{i_{q(d_j)}} \frac{dG_r}{G_r}$$

and $\sum_{i_1}^{i_{q(d_j)}} \deg G_r = d_j$, we have that \mathcal{F}_j^0 is given by

$$\omega_j^0 = F_0 \dots G_{i_1} \dots G_{i_{q(d_j)}} \dots F_m \left(\lambda_0 \frac{dF_0}{F_0} + \dots + \lambda_j \sum_{i_1}^{i_{q(d_j)}} \frac{dG_r}{G_r} + \dots + \lambda_m \frac{dF_m}{F_m} \right),$$

hence $\mathcal{F}_j^0 \in \text{Log}_n(d_0, \dots, \underline{\sigma}_{d_j}, \dots, d_m)$. Remark that, by the argument used in the proof of Theorem 2.3, we may choose the G_r 's to be smooth and in general position with the F_i 's, $i \neq j$. Doing this for each $0 \leq j \leq m$ we obtain the stated deformation \square

From this it follows

Theorem 2.5. — *The union $\bigcup_{\underline{d}} \text{Log}_n(d_0, \dots, d_m) \subset \text{Fol}(\mathbb{P}^n; \underline{d})$ is connected.*

Proof. — Given $\underline{d} = d_0, \dots, d_m$ and $\underline{d}' = d'_0, \dots, d'_{m'}$, with $\sum_{i=0}^m d_i = \sum_{j=0}^{m'} d'_j = d$, consider the complete partitions

$$\underbrace{\tau_{d_i} = 1, \dots, 1}_{d_i \text{ times}} \text{ of } d_i \text{ and } \underbrace{\tau_{d'_j} = 1, \dots, 1}_{d'_j \text{ times}} \text{ of } d'_j$$

for $0 \leq i \leq m$ and $0 \leq j \leq m'$.

Let $\mathcal{F} \in \text{Log}_n(d_0, \dots, d_m)$ and $\mathcal{G} \in \text{Log}_n(d'_0, \dots, d'_{m'})$ be, respectively, given by

$$\lambda_0 \widehat{F}_0 dF_0 + \dots + \lambda_m \widehat{F}_m dF_m \text{ and } \lambda'_0 \widehat{F}'_0 dF'_0 + \dots + \lambda'_{m'} \widehat{F}'_{m'} dF'_{m'}.$$

By Theorem 2.4 these can be deformed into

$$[g_1^0 \cdots g_{d_0}^0] \cdots [g_1^j \cdots g_{d_j}^j] \cdots [g_1^m \cdots g_{d_m}^m] \left[\lambda_0 \sum_1^{d_0} \frac{dg_r^0}{g_r^0} + \dots + \lambda_j \sum_1^{d_j} \frac{dg_r^j}{g_r^j} + \dots + \lambda_m \sum_1^{d_m} \frac{dg_r^m}{g_r^m} \right]$$

and

$$[l_1^0 \cdots l_{d'_0}^0] \cdots [l_1^j \cdots l_{d'_j}^j] \cdots [l_1^{m'} \cdots l_{d'_{m'}}^{m'}] \left[\lambda'_0 \sum_1^{d'_0} \frac{dl_r^0}{l_r^0} + \dots + \lambda'_j \sum_1^{d'_j} \frac{dl_r^j}{l_r^j} + \dots + \lambda'_{m'} \sum_1^{d'_{m'}} \frac{dl_r^{m'}}{l_r^{m'}} \right]$$

where the g_i^j 's and the l_i^j 's are homogeneous of degree 1. Both these foliations lie in

$$\text{Log}_n(\underbrace{1, 1, 1, 1, 1, \dots, 1, 1, 1, 1, 1}_{\sum_{i=0}^m d_i = \sum_{j=0}^{m'} d'_j = d \text{ times}})$$

and, since an irreducible algebraic set is connected, the result follows. □

Example 2.6. — Let $\mathcal{F} \in \text{Log}_n(d_0, \dots, d_m)$, suppose $\sum_{i=0}^m d_i = d \leq n$ and at least one d_i satisfies $d_i \geq 2$. By Theorem 1.5, the singular set $S(\mathcal{F})$ contains isolated points away from $\bigcup_{i < j} D_{ij}$. By Theorem 2.4, when we specialize

$$\text{Log}_n(d_0, \dots, d_m) \ni \mathcal{F} = \mathcal{F}^1 \xrightarrow{\mathcal{F}^t} \mathcal{F}^0 \in \text{Log}_n(\underbrace{1, 1, 1, \dots, 1, 1, 1}_{\sum_{i=0}^m d_i = d \text{ times}}),$$

\mathcal{F}^0 is such that, by Theorem 1.5 again, $S(\mathcal{F}^0)$ has only components of dimension $n - 2$. Hence, the isolated zeros of \mathcal{F}^t are absorbed by the $n - 2$ dimensional components of $S(\mathcal{F}^0)$.

Acknowledgments. — I'm grateful to Bruno Scárdua, Israel Vainsencher and the referee for useful comments, to IM - UNAM - Cuernavaca (Mexico), to IML - CNRS - Luminy (France) and to Ryukoku Univ. Kyoto (Japan), for hospitality.

References

- [1] P. ALUFFI – “Chern classes for singular hypersurfaces”, *Trans. Amer. Math. Soc.* **351** (1999), p. 3989–4026.
- [2] O. CALVO-ANDRADE – “Irreducible components of the space of holomorphic foliations”, *Math. Ann.* **299** (1994), p. 751–767.
- [3] O. CALVO-ANDRADE, D. CERVEAU, L. GIRALDO & A. LINS NETO – “Irreducible components of the space of foliations associated to the affine Lie algebra”, *Ergodic Theory Dynam. Systems* **24** (2004), p. 987–1014.
- [4] D. CERVEAU & A. LINS NETO – “Irreducible components of the space of holomorphic foliations of degree two in $\mathbb{C}P(n)$, $n \geq 3$ ”, *Ann. of Math. (2)* **143** (1996), p. 577–612.
- [5] D. CERVEAU, A. LINS NETO & S. J. EDIXHOVEN – “Pull-back components of the space of holomorphic foliations on $\mathbb{C}P(n)$, $n \geq 3$ ”, *J. Algebraic Geom.* **10** (2001), p. 695–711.
- [6] F. CUKIERMAN, M. G. SOARES & I. VAINSENCHER – “Singularities of logarithmic foliations”, *Compos. Math.* **142** (2006), p. 131–142.
- [7] W. FULTON – *Intersection theory*, Ergebnisse der Mathematik und ihrer Grenzgebiete (3), vol. 2, Springer, 1984.
- [8] R. HARTSHORNE – “Connectedness of the Hilbert scheme”, *Publ. Math. I.H.É.S.* **29** (1966), p. 5–48.
- [9] J. P. JOUANOLOU – *Équations de Pfaff algébriques*, Lecture Notes in Mathematics, vol. 708, Springer, 1979.

M. G. SOARES, Dep. Matemática - UFMG, Av. Antonio Carlos 6627, 31270-901 Belo Horizonte, Brazil • E-mail : msoares@mat.ufmg.br